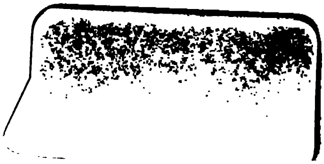


ELEMENTS

OF

AGRICULTURAL CHEMISTRY

AND

GEOLOGY.

BY

JAMES F. W. JOHNSTON, M.A., F.R.SS.L. & E.

Honorary Member of the Royal Agricultural Society of England, and Author of "Lectures on Agricultural Chemistry and Geology."

SIXTH EDITION.

WILLIAM BLACKWOOD AND SONS,
EDINBURGH AND LONDON.
MDCCCLII.

PRINTED BY WILLIAM BLACKWOOD AND SONS, EDINBURGH.

TO

PHILIP PUSEY, Esq., F.R.S., &c. &c.

LATE PRESIDENT OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.

My Dear Sir,

The object of the following [illegible] is to aid in diffusing a sounder and more extended [illegible] of elementary scientific principles, in their application [illegible] affairs, among the agricultural population of [illegible] acquainted with no one who has this object more [illegible] yourself. Permit me, therefore, to dedicate [illegible] as an evidence of sympathy with your wishes [illegible] mony, at the same time, of personal regard [illegible]

It is now nearly ten years since, in the [illegible] cated to you the First Edition of this [illegible] more pleasure in inscribing to you this [illegible] your own exertions in connection [illegible] Society, it has contribute[illegible] ledge of those modern [illegible] the science and pract[illegible] after nov[illegible] and exp[illegible] ed wit[illegible]

ADVERTISEMENT TO SIXTH EDITION.

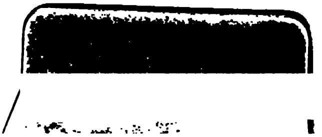
THE sale of upwards of ten thousand copies of this little book at home, and of very many more in the United States and in the British provinces, and the fact of its having been translated into nearly every European language, have imposed upon me the duty of making the present Edition still more worthy of the public favour.

I have, therefore, bestowed much pains upon the revision, have incorporated many new facts, introduced new sections, and added greatly to the number of the chapters, and have thus rendered many parts of the work more complete and methodical. On the whole, I believe it presents as full, fair, and plain a view of the present state of scientific agriculture as the limits of the Work admit of.

DURHAM, *November* 1852.

INTRODUCTION.

The scientific principles upon which the art of culture depends, have not hitherto been sufficiently understood or appreciated by practical men. Into the causes of this I shall not here inquire. I may remark, however, that if Agriculture is ever to be brought to that comparative state of perfection to which many other arts have already attained, it will only be by availing itself, as they have done, of the many aids which science offers to it. And if the practical man is ever to realise upon his farm all the advantages which science is capable of placing within his reach, he must become so far acquainted with the connection that exists between the art by which he lives and the sciences, especially of Chemistry, Geology, and Chemical Physiology, as to be prepared to listen with candour to the suggestions they are ready to make to him, and to attach their proper value to the explanations of his various processes which they are capable of affording.



CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

CHAPTER XXII.

ELEMENTS

OF

AGRICULTURAL CHEMISTRY,

ETC.

CHAPTER I.

Object of the farmer.—What chemistry, geology, and chemical physiology may do for agriculture.—Distinction between organic and inorganic substances.—The ash of plants and animals.—Simple and compound bodies.—What elementary bodies are contained in the organic part of soils, plants, and animals.—Properties of carbon, sulphur, phosphorus, hydrogen, oxygen, and nitrogen.—Relative proportions of these elementary bodies contained in plants and animals.—Meaning of chemical combination and chemical decomposition.

THE object of the practical farmer is to raise from a given extent of land the largest quantity of the most valuable produce at the least cost, in the shortest period of time, and with the least permanent injury to the soil. Chemistry, Geology, and Chemical Physiology throw light on every step he takes, or ought to take, in order to effect this main object.

SECTION I.—WHAT CHEMISTRY, GEOLOGY, AND CHEMICAL PHYSIOLOGY MAY HOPE TO DO FOR AGRICULTURE.

But there are certain definite objects which, in their connection with agriculture, these sciences hope to attain.

Thus, without distinguishing the special province of each, they propose generally :—

1°. *To collect, to investigate, and, if possible, to explain all known facts in practical husbandry.*—This is their first duty—a laborious, difficult, but important one. Many things which are received as facts in agriculture prove to be more or less untrue when investigated and tested by experiment. Many ascertained facts appear inexplicable to the uninstructed—many even opposite and contradictory, which known principles clear up and reconcile—yet there are many more which only prolonged research can enable us to explain!

2°. *From observations and experiments made in the field or in the laboratory, to deduce principles which may be more or less applicable in all circumstances.*—Such principles will explain useful practices, and confirm their propriety. They will also account for contradictory results, and will point out the circumstances under which this or that practice may most prudently and most economically be adopted.

Armed with the knowledge of such principles, the instructed farmer will go into his fields as the physician goes to the bedside of his patient,—prepared to understand symptoms and appearances he has never before seen, and to adapt his practice to circumstances which have never before fallen under his observation.

To deduce principles from collections of facts is attended with much difficulty in all departments of knowledge. In agriculture it is at present an unusually difficult task. Observations and experiments in the field have hitherto been generally made with too little care, or recorded with too little accuracy, to justify the scientific man in confidently adopting them as the basis of his reasonings. A new race, however, of more careful observers and more

accurate experimenters is now springing up. By their aid, the advance of sound agricultural knowledge cannot fail to be greatly promoted.

3°. *To suggest improved, and, perhaps, previously unthought-of methods of fertilising the soil.*—A true explanation of twenty known facts or results, or useful practices, should suggest nearly as many more. Thus the explanation of old errors will not only guard the practical man from falling into new ones, but will suggest direct improvements he would not otherwise have thought of. So, also, the true explanation of one useful practice will point out other new practices, which may safely and with advantage be adopted.

4°. *To analyse soils, manures, and vegetable products.*—This is a most laborious department of the duties which agriculture expects chemistry to undertake in her behalf.

a. Soils.—The kind and amount of benefit to be derived from the analyses of soils are becoming every day more apparent. We cannot, indeed, from the results of an analysis, prescribe in every case the kind of treatment by which a soil may at once be rendered most productive. In many cases, however, certain wants of the soil are directly pointed out by analysis; in many others, modes of treatment are suggested, by which a greater fertility is likely to be produced,—and as our knowledge of the subject extends, we may hope to obtain, in every case, some useful directions for the improvement or more profitable culture of the land.

b. Manures.—Of the manures we employ, too much cannot be known. An accurate knowledge of these will guard the practical man against an improvident waste of any of those natural manures which are produced upon his farm—thus lessening the necessity for foreign manures, by introducing a greater economy of those he already

possesses. It will also protect him against the ignorance or knavery of the manure manufacturer. The establishment of such manufactories, conducted by skilful and honourable men, is one of the most important practical results to which the progress of scientific agriculture is likely to lead. And if it cannot prevent unscrupulous adulterators from engaging in this new traffic, chemistry can at least detect and expose their frauds.

c. Vegetable Products.—In regard, again, to the products of the soil, few things are now more necessary than a rigorous analysis of all their parts. If we know what a plant contains, we know what elementary bodies it takes from the soil, and consequently what the soil *must* contain if the plant is to grow upon it in a healthy manner,—that is, we shall know, to a certain extent, how to manure it.

On the other hand, in applying vegetable substances to the feeding of stock, it is of equal importance to know what they severally contain, in order that a skilful selection may be made of such kinds of food as may best suit the purposes we intend them to serve.

5°. *To explain how plants grow and are nourished, and how animals are supported and most cheaply fed.* —What food plants require, and at different periods of their growth, whence they obtain it, how they take it in, and in what forms of chemical combination? Also, what kind and quantity of food the animal requires, what purposes different kinds of food serve in the animal economy, and how a given quantity of any variety of food may be turned to the best account? What questions ought more to interest the practical farmer than these?

Then there are certain peculiarities of soil, both physical and chemical, which are best fitted to promote the growth of each of our most valuable crops. There are

also certain ways of cultivating and manuring, and certain kinds of manure which are specially favourable to each, and these again vary with every important modification of climate. Thus chemical physiology has much both to learn and to teach in regard to the raising of crops.

So, different kinds and breeds of domestic animals thrive best upon different kinds of food, or require different proportions of each, or to have it prepared in different ways, or given at different times. Among animals of the same species also, the growing, the full-grown, the fattening, and the milking animal, respectively require a peculiar adjustment of food in kind, quantity, or form. All such adjustments the researches of chemistry and physiology alone enable us accurately to make.

6°. *To test the opinions of theoretical men.*—Erroneous opinions lead to grave errors in practice. Such incorrect opinions are not unfrequently entertained and promulgated even by eminent scientific men. They are in this case most dangerous and most difficult to overturn; so that against these unfounded theories the farmer requires protection, no less than against the quackery of manufactured manures. It is only on a basis of often repeated, skilfully conducted, and faithfully recorded experiments, made by instructed persons, that true theories can ever be successfully built up. *Hence the importance of experiments in practical agriculture.*

Such are the principal objects which chemistry, aided by geology and physiology, either promises or hopes to attain. In no district, however, will the benefits she is capable of conferring upon agriculture be fully realised, unless her aid be really sought for, her ability rightly estimated, and her interference earnestly requested. In other words, what we already know, as well as what we are every day learning, must be adequately diffused

among the agricultural body, and in every district means must be adopted for promoting this diffusion. It is in vain for chemistry and the other sciences to discover or suggest, unless her discoveries and suggestions be fully made known to those whose benefit they are most likely to promote.

SECTION II.—OF ORGANIC AND INORGANIC MATTER, AND OF THE ORGANIC AND INORGANIC PARTS OF ANIMALS, PLANTS, AND SOILS.

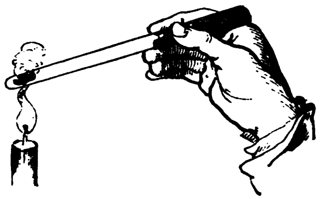
In the prosecution of his art, two distinct classes of substances engage the attention of the practical farmer—the *living* animals and crops he raises, and the *dead* soils from which the latter are gathered. If he examine any fragment of an animal or vegetable, either living or dead, —a piece of flesh or wood, for example,—he will observe that it exhibits pores of various kinds arranged in a certain order; that it has a species of internal structure; that it has various parts or *organs;* in short, that it is what physiologists term *organised.* If he examine, in like manner, a lump of earth or rock, he will perceive no such structure. To mark this distinction, the parts of animals and vegetables, either living or dead—whether entire or in a state of decay—are called *organic* bodies, while earthy and stony substances are called *inorganic* bodies.

Organic substances are more or less readily burned away and dissipated by heat in the open air; inorganic substances are generally fixed and permanent in the fire.

Now the crops which grow upon the land, as well as the soil in which they are rooted, contain a portion of both of these classes of substances. In all fertile soils there exists from 3 to 10 per cent of vegetable or other

matter, of *organic* origin. If we heat a portion of such a soil to redness in the open air, as in the annexed, (fig. 1,) this organic matter will burn away, leaving the inorganic or mineral matter behind. By this burning, most soils are changed in colour, but, if previously dried, are not materially diminished in bulk. The inorganic matter forms by far their largest part.

Fig. 1.



All vegetables, again, as they are collected for food, leave, when burned, a sensible quantity of *inorganic* ash; but of them it forms only a small part. Wood leaves about a ½ per cent, grain 2 or 3 per cent, straw about 5 per cent; and only in rare cases does the ash left amount to 15 or 20 per cent of the weight of a vegetable substance. Hence, when a handful of wheat, wheat straw, hay, &c., is burned in the air, a comparatively small weight of matter only remains behind. Every one is familiar with this fact who has seen the small bulk of ash that is left when weeds, or thorn-bushes, or trees, are burned in the field, or when a hay or corn stack is accidentally consumed. Yet this ash is very important to the plant, and the study of its true nature throws much light, as we shall hereafter see, on the practical management of the land on which any given crop is to be made to grow. It strikes us also as being important in quantity, when we consider how much may be contained in an entire crop. Thus the quantity of ash left by a ton of wheat straw is sometimes as much as 360 lb., and by a ton of oat straw as much as 200 lb. A ton of the grain of wheat leaves on an average about 45 lb., of the

grain of oats about 9 lb., and of oak wood only 4 or 5 lb.

Animal substances also leave a proportion of ash when burned in the air. Dry flesh and hair leave about 5 per cent of their weight of inorganic ash; dry bones more than half their weight.

Generally, therefore, the soil contains little organic and much inorganic or mineral matter — the plant much organic and little mineral — the animal, in its soft parts, little, in its hard or solid parts, much mineral matter.

SECTION III.—OF SIMPLE OR ELEMENTARY AND COMPOUND BODIES.

The various kinds of organic and inorganic matter of which soils, plants, and animals consist, are distinguished by chemists into two groups. Those which, by the agency of heat, or by any chemical or other means, can be separated into two or more unlike kinds of matter, are called *compound* bodies — those which cannot be so separated, are called *simple* or *elementary* bodies.

Gold, iron, sulphur, and pure charcoal are *simple* substances. They cannot by any known means be separated or resolved into more than one substance.

Wood, flesh, limestone, sand, &c., are *compound* substances. We are acquainted with methods by which they can each be split up into two or more substances different from each other, and from the wood or flesh, &c., from which they are obtained.

Of simple or elementary bodies sixty-four are at present known to chemists. All the other forms of matter which occur in the animal, vegetable, or mineral kingdoms are compound.

SECTION IV. — OF THE ELEMENTARY SUBSTANCES OF WHICH THE ORGANIC PART OF SOILS, PLANTS, AND ANIMALS CONSISTS.

The organic or combustible part of soils, plants, and animals is composed almost exclusively of four elementary substances, known to chemists by the names of carbon, hydrogen, oxygen, and nitrogen. It usually contains also a minute proportion of sulphur and phosphorus.

Of these, carbon, sulphur, and phosphorus are solid substances; while hydrogen, oxygen, and nitrogen are gases, or peculiar kinds of air. Their properties are as follows:—

1. CARBON.—When wood is burned in a covered heap, as is done by the charcoal-burners,—or is distilled in iron retorts, as in making wood-vinegar, — it is charred, and is converted into common wood charcoal. This charcoal is the most usual and best known variety of carbon. It is black, soils the fingers, and is more or less porous, according to the kind of wood from which it has been formed. Coke obtained by charring or distilling coal is another variety. It is generally denser or heavier than charcoal, though usually less pure. Black lead is a third variety, still heavier and more impure. The diamond is the only form in which carbon occurs in nature in a state of perfect purity.

This latter fact, that the diamond is pure carbon—that it is essentially the same substance with the finest and purest lamp-black—is very remarkable; but it is only one of the numerous striking circumstances that every now and then present themselves before the inquiring chemist.

Charcoal, the diamond, lamp-black, and all the other

forms of carbon, burn away more or less slowly when heated to redness in the air or in oxygen gas, and are converted into a kind of gas known by the name of *carbonic acid gas.* The impure varieties, when burned, leave behind them a greater or less proportion of ash.

2. SULPHUR is a well-known solid substance of a light yellow colour, and faint peculiar odour. It burns with a pale-blue flame, and in burning gives off fumes possessed of a strong pungent characteristic smell.

3. PHOSPHORUS is a yellowish waxy substance of a peculiar smell, which smokes in the air, shines in the dark, takes fire by mere rubbing, and burns with a large bright flame and much white smoke. Like sulphur, it exists in all plants and animals, though in comparatively small quantity. Like sulphur, also, it is employed largely in the arts, especially in the manufacture of lucifer matches.

Fig. 2.

4. HYDROGEN.—If oil of vitriol (sulphuric acid) be mixed with twice its bulk of water, and be then poured upon iron filings, or upon small pieces of zinc, the mixture will speedily begin to boil up, and bubbles of gas will rise to the surface of the liquid in great abundance. These are bubbles of hydrogen gas.

If the experiment be performed in a bottle, the hydrogen which is produced will gradually drive out the atmospheric air it contained, and will itself take its place. If a taper be tied to the end of a wire, and, when lighted, be introduced into the bottle, (fig. 2,) it will be instantly extinguished; while the hydrogen will take fire, and burn at the mouth of the bottle

with a pale yellow flame. If the taper be inserted before the common air is all expelled, the mixture of hydrogen and common air will burn with an explosion more or less violent, and may even shatter the bottle and produce serious accidents. This experiment, therefore, ought to be made with caution. It may be more safely performed in a common tumbler, (fig. 3,) covered closely by a plate, till a sufficient quantity of hydrogen is collected, when, on the introduction of the taper, the light will be extinguished, and the hydrogen will burn with a less violent explosion. Or the gas may be prepared in a retort, and collected over water, as shown in fig. 4.

Fig. 3.

This gas is the lightest of all known substances, rising through common air as wood does through water. Hence, when confined in a bag made of silk, or other light tissue, it is capable of sustaining heavy substances in the air, and even of carrying them up to great heights. For this reason it is employed for filling and elevating balloons.

Hydrogen gas is not known to occur anywhere in nature in any sensible quantity in a *free state.* It is very abundant in water, and in many other substances, in what by chemists is called a *state of combination.* (See pages 16 and 25.)

5. Oxygen.—When strong oil of vitriol is poured upon black oxide of manganese, and heated in a glass retort, (fig. 4,) or when a mixture of chlorate of potash with an equal weight of oxide of manganese, or when chlorate of potash alone, or red oxide of mercury alone, is so heated —or when saltpetre, or the black oxide of manganese, is heated alone in an iron bottle,—in all these cases a kind

of air is given off, to which the name of oxygen gas is

Fig. 4.

given. It is obtained with the greatest ease, rapidity, and purity, from the mixture of chlorate of potash and oxide of manganese.

Fig. 5.

A very elegant method of preparing the gas is to put a few grains of *red oxide of mercury* into a tube, and apply the heat of a lamp as in fig. 5. Oxygen gas will be given off while minute globules of metallic mercury will condense on the cool part of the tube. The presence of oxygen in the tube is shown by introducing into one end of it a half-kindled match, when it will be seen to burn up brilliantly.

It is the characteristic property of this gas, that a taper, when introduced into it, burns with great rapidity, and with exceeding brilliancy, and continues to burn till either the whole of the gas disappears or the taper is entirely consumed. In this respect it differs both from hydrogen and from common air. If a living animal is introduced into this gas, its circulation and its breathing

become quicker—it is speedily thrown into a fever—it lives as fast as the taper burned—and, after a few hours, dies from excitement and exhaustion. This gas is not lighter, as hydrogen is, but is about one-ninth part heavier than common air.

In the atmosphere, oxygen exists in the state of gas. It forms about one-fifth of the bulk of the air we breathe, and is the substance which, in the air, supports all animal life, and the combustion of all burning bodies. It is necessary also to the growth of plants, so that were it by any cause suddenly removed from the atmosphere of our globe, every living thing would perish, and all combustion would become impossible.

6. NITROGEN.—This gas is very easily prepared. Dissolve a little green copperas in water, and pour the solution into a flask, or crystal bottle, provided with a good cork. Add a little of the hartshorn of the shops (liquid ammonia) till it is quite muddy, put in the cork tight, and shake the bottle well for five minutes. Loosen the cork a little without removing it, so as to allow air to enter the bottle. Cork tight again and shake as before. Repeat this as often as the loosening of the cork appears to admit any air, and after finally shaking it, allow it to stand for a few minutes. The air now in the bottle is nearly pure nitrogen gas.

If a lighted taper be introduced into the bottle, it will be extinguished by this gas, but no other effect will follow. The gas itself does not take fire as hydrogen does. Or if a living animal be introduced into it, breathing will instantly cease, and it will drop without signs of life.

This gas possesses no other remarkable property. It is a very little lighter than common air, (as 97½ to 100,) and exists in large quantity in an uncombined state in the atmosphere only. Of the air we breathe it forms nearly

four-fifths of the entire bulk — the remainder being oxygen. In the process above described for preparing the gas, the oxygen is absorbed by the iron, and the nitrogen left behind.

These three gases are incapable of being distinguished from common air, or from each other, by the ordinary senses; but by the aid of the taper they are readily recognised. Hydrogen extinguishes the taper, but itself takes fire; nitrogen simply extinguishes it; while in oxygen the taper burns rapidly and with extraordinary brilliancy.

SECTION V.—PROPORTIONS OF THESE ELEMENTARY SUBSTANCES CONTAINED IN THE ORGANIC PART OF PLANTS AND ANIMALS.

Of the one solid substance, carbon, and the three gases, hydrogen, oxygen, and nitrogen, above described, the organic part of all vegetable and animal bodies is essentially made up. In those organic substances which contain nitrogen, sulphur and phosphorus also are present, but generally in minute proportion.

But the organic part of plants contains these four substances in very different proportions. Thus, of all the vegetable productions which are gathered as food by man or beast, in their *dry state*, the

Carbon forms nearly *one-half* by weight,
Oxygen rather more than *one-third*,
Hydrogen little more than 5 *per cent*,
Nitrogen from ½ to 4 *per cent*,
Sulphur 1 to 5 *per cent*,
Phosphorus about a *thousandth part*.

This is shown in part by the following table, which ex-

hibits the actual composition of 1000 lb. of some varieties of the more common crops, when made *perfectly dry*:—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
Hay, .	458 lb.	50 lb.	387 lb.	15 lb.	90 lb.
Red Clover Hay,	474	50	378	21	77
Potatoes, .	440	58	447	15	40
Wheat, .	461	58	434	23	24
Wheat Straw,	484	53	389½	3½	70
Oats, .	507	64	367	22	40
Oat Straw,	501	54	390	4	51

It is to be observed, however, that in drying by a gentle heat, 1000 lb. of common hay from the stack lost 158 lb. of water; of clover hay, 210 lb.; of potatoes wiped dry externally, 759 lb.;* of wheat, 145 lb.; of wheat straw, 260 lb.; of oats, 151 lb.; and of oat straw, 287 lb. The above table represents their composition when thus made perfectly dry.

The bodies of animals contain also a large proportion of water; but the dry matter of their bodies, as a whole, is distinguished from that of plants, by containing a larger proportion of nitrogen, sulphur, and phosphorus. Some parts of the bodies of animals are particularly rich in these ingredients. Thus—

Dry *lean muscle* contains 12 to 14 per cent of *nitrogen*,
Dry *hair* or *wool* about 5 per cent of sulphur; and
Dry *bone* about 6 per cent of phosphorus.

But in animals, as in plants, the chief constituents are carbon and oxygen. Thus, lean beef, blood, white of egg, and the curd of milk, when quite dry, consist in 100 parts of about—

	Per cent.
Carbon, ...	55
Hydrogen, ...	7
Nitrogen, ...	16
Oxygen, with a little sulphur and phosphorus,	22
	100

* Potatoes contain about four-fifths of their weight of water, or five tons of roots contain nearly four tons of water. Turnips contain sometimes upwards of *nine-tenths* of their weight of water.

SECTION VI.—OF CHEMICAL COMBINATION AND CHEMICAL DECOMPOSITION.

1°. If the three kinds of air above spoken of be mixed together in a bottle, no change will take place; and if charcoal in fine powder be added to them, still no new substance will be produced. Or if we take the ash left by a known weight of hay or of wheat straw, and mix it with the proper quantities of the four elementary substances — carbon, hydrogen, oxygen, and nitrogen—as shown in the above table, we shall be unable by this means to form either hay or wheat straw. The elements of which vegetable substances consist, therefore, are not merely *mixed* together, they are united in some closer and more intimate manner. To this more intimate state of union the term *chemical combination* is applied—the elements are said to be *chemically combined.*

Thus, when charcoal is burned in the air, it slowly disappears, and forms, as already stated, (p. 10,) a kind of air known by the name of carbonic acid gas, which rises into the atmosphere and diffuses itself through it. Now, this carbonic acid is formed by the *union* of the carbon (charcoal) while burning, with the oxygen of the atmosphere, and in this new air the two elements, carbon and oxygen, are *chemically combined.*

Again, if hydrogen be burned in the air by means of a common gas jet, (see p. 25,) water is formed, and the hydrogen, and a portion of the oxygen of the atmosphere, disappear together. The two gases have *combined chemically* with each other, and formed water.

2°. On the other hand, if a piece of wood, or a bit of straw, in which the elements are already chemically combined, be burned in the air, these elements are separated,

and made to assume new states of combination, in which new states they escape into the air and become invisible. When a substance is thus changed, and converted or separated into other substances by the action of heat, or in any other way, it is said to be *decomposed.* If it more gradually decay and perish, as animal and vegetable substances do, by exposure to the air and moisture, it is said to undergo slow *decomposition.*

When, therefore, two or more substances unite together, so as to form a third, possessing properties different from both, they enter into chemical union—they form a *chemical combination* or chemical *compound.* And when, on the other hand, a compound body is so changed as to be converted into two or more substances different from itself, it is *decomposed.* Thus carbon, hydrogen, and oxygen undergo a chemical combination in the interior of the plant during the formation of wood—while wood, again, is decomposed, when in the retort of the vinegar-maker it is converted among other substances into charcoal and wood-vinegar. So the flour of grain is decomposed when the brewer or distiller converts it into ardent spirits; and so in the experiment described in section IV. for preparing oxygen gas from red oxide of mercury, the oxide is decomposed by the heat, and is resolved into its two constituent elements, oxygen and metallic mercury.

CHAPTER II.

Forms in which the organic elements, carbon, hydrogen, oxygen, nitrogen, sulphur, and phosphorus, enter into plants.—Properties of the carbonic, humic, ulmic, geic, and crenic acids, and of humine and ulmine. —Of water, and its relations to vegetable life.—Of ammonia, its properties and production in nature. — Of other organic alkalies containing nitrogen. — Of nitric acid, and its production in the air and in the soil — Composition of the atmosphere. — Of sulphuric and phosphoric acids.

SECTION I.—FORMS IN WHICH THE ORGANIC ELEMENTS, CARBON, HYDROGEN, OXYGEN, NITROGEN, &c., ENTER INTO PLANTS.

It is from their food that plants derive the carbon, hydrogen, oxygen, and nitrogen, as well as the sulphur and phosphorus, of which their organic part consists. This food enters partly by the minute pores of their roots, and partly by those which exist in the green parts of the leaf and of the young twig. The roots bring up food from the soil, the leaves take it in directly from the air.

Now, as the pores in the roots and leaves are very minute, carbon (charcoal) cannot enter them in a *solid* state; and as it does not dissolve in water, it cannot, in the state of simple carbon, be any part of the food of plants. The same is true of sulphur and phosphorus. Again, hydrogen gas neither exists in the air nor usually in the soil; so that, although hydrogen is always found in the substance of plants, it does not enter them in the state of gas. Oxygen, on the other hand, exists in the air, and *is* directly absorbed both by the leaves and by the roots of plants; while nitrogen, though it forms a large

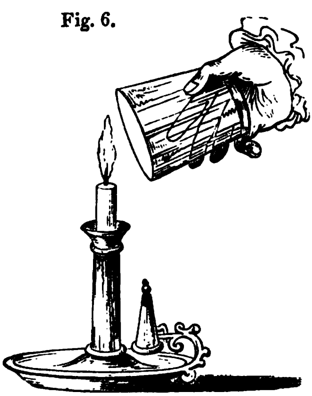
part of the atmosphere, is not known to enter *directly* into plants in any considerable quantity.

The whole of the carbon and hydrogen, therefore, and the greater part of the oxygen and nitrogen also, enter into plants in a state of *chemical combination* with other substances. The carbon is taken up chiefly in the state of carbonic acid, and of certain other soluble compounds which exist in the soil; the hydrogen and oxygen in the form of water; the nitrogen chiefly, it is supposed, in those of ammonia, of certain other soluble substances containing nitrogen and of nitric acid; and the sulphur and phosphorus in those of sulphuric and phosphoric acids. It will be necessary, therefore, briefly to describe these several compounds.

SECTION II. — OF THE CARBONIC, HUMIC, ULMIC, GEIC, AND CRENIC ACIDS.

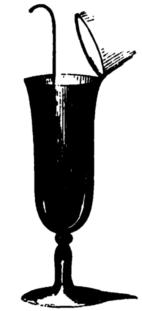
1. Carbonic Acid.—If a few pieces of chalk or limestone, or of common soda, be put into the bottom of a tumbler, and a little spirit of salt (muriatic acid) be poured upon them, a boiling up or *effervescence* will take place, and a gas will be given off, which will gradually collect and fill the tumbler; and when produced very rapidly, may even be seen to run over its edges. This gas is carbonic acid. It cannot be distinguished from common

Fig. 6.



air by the eye; but if a lighted taper be plunged into it, the flame will immediately be extinguished, while

Fig. 7.



the gas will remain unchanged. This kind of air is so heavy, that it may be poured from one vessel into another, and its presence in the second vessel recognised as before by the use of the taper. Or it may be poured upon a lighted candle, which it will instantly extinguish, (fig. 6.) This gas has also a peculiar odour, and is exceedingly suffocating, so that if a living animal be introduced into it, life immediately ceases. It is absorbed by water—a pint of water absorbing or dissolving a pint of the gas, and acquiring a faintly acid taste.

This gas derives its name of acid from this taste, which it imparts to water, and from its property of reddening vegetable blue colours, and of combining with alkaline* substances to form *carbonates*.

Fig. 8.

The former property may be shown by passing a stream of the gas through a decoction of red cabbage—as in fig. 8—when the liquid will gradually become red; the latter, by putting lime water into the glass instead of the decoction of red cabbage, when the stream of gas will render it milky, forming *carbonate of lime*.

* *Acids* have generally a sour taste like vinegar, and redden vegetable blues. Alkalies, again, have a peculiar taste called *alkaline*, of which the taste of common soda or of hartshorn are examples; they restore the blue colour to vegetable blues which have been reddened by an acid, and they unite with acids to form chemical combinations, known by the name of salts or saline combinations.

Carbonic acid gas exists in the atmosphere; it is given off from the lungs of all living animals while they breathe; it is also produced largely during the burning of wood, of coal, and of all other combustible bodies, so that an unceasing supply of it is perpetually being poured into the air. Decaying animal and vegetable substances also give off this gas, and hence it is always present in greater or less abundance in the soil, and especially in such soils as are rich in vegetable matter. It is produced during the fermentation of malt liquors, or of the expressed juices of different fruits, such as the apple, the pear, the grape, or the gooseberry — and the briskness of such fermented liquors is due to the escape of carbonic acid gas. From fermenting dung and compost heaps it is also given off; and when put into the ground, farm-yard manure imparts much carbonic acid to the soil and to the roots of plants.

Carbonic acid consists of carbon and oxygen only, combined together in the proportion of 28 of the former to 72 of the latter. Or 100 lb. of carbonic acid contain 28 lb. of carbon and 72 lb. of oxygen.

It combines with potash, soda, lime, magnesia, ammonia, &c., forming *carbonates* of these bases.

2. Humic and Ulmic Acids.—The soil always contains a portion of decaying vegetable matter, (called *humus* by some writers,) and such matter is always added to it when it is manured from the farm-yard or the compost heap. During the decay of this vegetable matter, carbonic acid, as above stated, is given off in large quantity, but other substances are also formed at the same time. Among these are the two to which the names of *humic* and *ulmic* acids are respectively given. Both of these acids contain much carbon,—they are both capable

of entering the roots of plants, and both, in favourable circumstances, help to feed the plant.

In peat bogs two distinct kinds of turf are frequently recognised—a light, porous, brown-coloured, and a dense, compact, black variety. The former abounds in reddish-brown *ulmic*, the latter in brownish-black *humic* acid. These acids may readily be extracted from the peat by means of potash, soda, or ammonia, in solutions of which they easily dissolve.

Thus if the common soda of the shops be dissolved in water, and a portion of a rich vegetable soil, or a bit of peat, be put into this solution, and the whole then boiled, a brown liquid is obtained. If to this brown liquid, spirit of salt (muriatic acid) or vinegar be added till it is sour to the taste, a brown flocky tasteless powder falls to the bottom. This brown substance is humic or ulmic or geic acid, or a mixture of all the three. In our cultivated soils, the humic is more abundant than the ulmic acid.

The quantity of these mixed acids, extracted in this way from three rich soils, was respectively 4¼, 5¼, and 8½ per cent. In most of our arable soils, however, the proportion present is considerably less.

3. Geic Acid.—The geic acid resembles the above acids in appearance, but contains more oxygen. Like them it exists in the soil in variable quantity, and may be extracted from it by solutions of potash, soda, or ammonia, and is thrown down from these solutions by the addition of an acid.

These three acids have so strong a tendency to combine with ammonia, that it is almost impossible to obtain them free from this substance. In the soil they absorb it whenever it is present, and if exposed to the air in a moist state, they drink it in from the atmosphere, if any happen

to be floating in their neighbourhood. Hence the utility of partially dried peat for absorbing liquid manure, or for mixing with or covering fermenting compost heaps.

All the three acids above named are sparingly soluble in water, and, therefore, in their uncombined state can afford little direct nourishment to plants. They form compounds with lime, magnesia, and oxide of iron, which are also very sparingly soluble, and enter little into the roots of plants. They all dissolve readily, however, when they are combined with potash, soda, or ammonia. And as the latter substance especially is produced, and is always present in the soil, and as these acids attract it very strongly, there is good reason for believing that they are frequently rendered soluble by it, and that in this way ulmic, humic, and geic acids contribute directly to the nourishment of our cultivated crops.

4. Crenic and Apocrenic Acids.—By these names are distinguished two other acid substances which exist in the soil, and in a greater degree, perhaps, and more directly, promote the growth of plants. They exist in the water of all bogs and morasses, and are often met with in considerable quantity in the water of springs, especially in such as form an ochrey deposit when exposed to the air. They are produced from the humic and ulmic acids by the absorption of more oxygen from the atmosphere, and, like them, eagerly combine with ammonia; but they are lighter in colour, and much more soluble in water.

When rich soil is boiled in carbonate of soda, as above described, and the humic, ulmic, and geic acids are thrown down by the addition of muriatic acid, the crenic and apocrenic acids remain still in the solution, and may be separated by further processes which it is unnecessary here to describe.

All the above acids, and especially the two latter, exist

in greater or less quantity in the rich brown liquor of the farm-yard, which is so often allowed to run to waste. They are produced, also, during the decay of the mixed animal and vegetable manure we add to the soil, and yield to the plant a portion of that supply of organic food which it must necessarily receive from the soil.

5. HUMINE AND ULMINE are the names given to certain insoluble black substances formed in the soil along with the humic and other acids during the decay of vegetable matter. One of the ways in which lime acts beneficially upon the soil is supposed to be by *disposing* these insoluble matters to enter into new states of combination, in which they may become soluble, and thus capable of entering into the roots of plants.*

Of the important substances above described, I may further remark—

a. That the ulmic acid is the first formed from the decay of vegetable matter. Hence, in peat bogs the red turf is usually found nearest to the surface.

b. That the humic acid is formed from the ulmic by the absorption of more oxygen from the atmosphere. It consists of carbon and water only. (See page 53.)

c. That the geic contains more oxygen than the humic acid, and is formed from it by the absorption of a further quantity of oxygen from the air, or from the water with which it is in contact.

d. That the crenic and apocrenic acids contain still more oxygen, and, along with other substances produced in the soil, are formed by the union of the geic acid with another proportion of oxygen.

Thus decaying vegetable matter appears first to form

* See in the Chapter "On the Use of Lime" the Sections which treat of the chemical action of lime when applied to the soil.

the ulmic, next the humic, then the geic, after that the crenic and apocrenic acids. We do not know how many other compounds may succeed to these by the union of their elements with more and more oxygen, before they are entirely resolved into carbonic acid,—the final state to which all these changes ultimately lead.

These successive absorptions of oxygen by the decaying vegetable matter, promote the production of ammonia in the soil, as well as of nitric acid. This fact will be more clearly explained in section VI.

SECTION III.—OF WATER, ITS COMPOSITION, AND ITS RELATIONS TO VEGETABLE LIFE.

If hydrogen be prepared in a bottle, in the way already described, (p. 10,) and a gas-burner be fixed into its mouth, the hydrogen may be lighted, and will burn as it escapes into the air, (fig. 9.) Held over this flame, a cold tumbler will become covered with dew, or with little drops of water. This water is *produced* during the burning of the hydrogen; and as its production takes place in pure oxygen gas as well as in the open air, which contains oxygen—a portion of the oxygen and hydrogen alone disappearing — the water formed must contain the hydrogen and oxygen which disappear, or *must consist of hydrogen and oxygen only.*

Fig. 9.

This is a very interesting fact; and were it not that chemists are now familiar with many such, it could not

fail to appear truly wonderful that the two gases, oxygen and hydrogen, by uniting together, should form water—a substance so very different in its properties from either. Water consists of 1 of hydrogen united to 8 of oxygen by weight; or every 9 lb. of water contain 8 lb. of oxygen and 1 lb. of hydrogen.

Water is so familiar a substance, that it is unnecessary to dwell upon its properties. When pure, it has neither colour, taste, nor smell. At 32° of Fahrenheit's * scale, (the freezing point,) it solidifies into ice; and at 212° it boils, and is converted into steam. It possesses two other properties, which are especially interesting in connection with the growth of plants.

1*st.* If sugar or salt be put into water, they disappear, or are *dissolved.* Water has the power of thus dissolving numerous other substances in greater or less quantity. Hence, when the rain falls and sinks into the soil, it dissolves a portion of the soluble substances it meets with in its way, both through the air and through the soil, and rarely reaches the roots of plants in a pure state. So waters that rise up in springs are rarely pure. They always contain earthy and saline substances in solution, and these they carry with them when they are sucked in by the roots of plants.

It has been above stated, that water absorbs (dissolves) its own bulk of carbonic acid; it dissolves also smaller quantities of the oxygen and nitrogen of the atmosphere; and hence, when it meets any of these gases in the soil, it becomes impregnated with them, and conveys them into the plant, there to serve as a portion of its food.

In nature, water never occurs in a pure state. It generally contains both gaseous and saline substances in a state of solution; and this, no doubt, is a wise provision

* This is the scale of the common thermometer used in this country.

by which the food of plants is constantly renewed and brought within their reach.

2d. Water, as we have shown above, is composed of oxygen and hydrogen, and by certain chemical processes it can readily be resolved or decomposed *artificially* into these two gases. The same thing takes place *naturally* in the interior of the living plant. The roots and leaves absorb the water ; but if in any part of the plant hydrogen be required for the formation of the substance which it is the function of that part to produce, a portion of the water of the sap is decomposed either directly or indirectly, and its hydrogen worked up, while its oxygen is set free, or converted to some other use. So, also, where oxygen is required, and cannot be obtained from some more ready source, water is decomposed, the oxygen made use of, and the hydrogen liberated. Water, therefore, which abounds in the vessels of all growing plants, if not directly converted into the substance of the plant, is yet a ready and ample source from which a supply of either of the elements of which it consists may at any time be obtained.

It is a beautiful adaptation of the properties of this all-pervading compound—water—that its elements should be so fixedly bound together as rarely to separate in external nature, and yet to be thus at the command and easy disposal of the vital powers of the humblest order of living plants.

SECTION IV.—OF AMMONIA, ITS PROPERTIES AND PRODUCTION IN NATURE.

If the sal-ammoniac, or the sulphate of ammonia of the shops, be mixed with quick-lime, a powerful odour is immediately perceived, and an invisible gas is given off,

which strongly affects the eyes. This gas is ammonia. Water dissolves or absorbs it in very large quantity, and this solution of the gas in water forms the common hartshorn of the shops. The white solid smelling-salts of the shops (carbonate of ammonia) are a compound of ammonia with carbonic acid and a little water.

Ammonia consists of nitrogen and hydrogen only, in the proportion of 14 of the former to 3 of the latter by weight; or 17 lb. of ammonia contain 14 lb. of nitrogen and 3 lb. of hydrogen.

The decay of animal substances is an important natural source of this compound. During the putrefaction of dead animal bodies, ammonia is invariably given off. From the animal substances of the farm-yard it is evolved during their decay or putrefaction, as well as from all solid and liquid manures of animal origin.

Ammonia is naturally formed, also, during the decay of vegetable substances in the soil. This happens in one or other of three ways.

a. As in animal bodies, by the direct union of the nitrogen with a portion of the hydrogen of which they consist.

b. Or by the combination of a portion of the hydrogen of the decaying plants with the nitrogen of the air.

c. Or when they decompose in contact, at the same time, with both air and water—by their taking the oxygen of a quantity of the water, and disposing its hydrogen at the moment of liberation, to combine with the nitrogen of the air, and form ammonia.

The production of ammonia by either of the two latter modes, takes place most abundantly where the oxygen of the air does not gain very ready access. Such are open subsoils, in which vegetable matter abounds. And thus one of the benefits which follow from thorough draining

and subsoil ploughing is, that the roots penetrate and fill the subsoil with vegetable matter, which, by its decay in the confined atmosphere of the subsoil, gives rise to this production of ammonia. When thus formed in the soil, it is at once absorbed and retained by the humic and ulmic acids already described, renders them soluble, and enters with them into the roots of living plants.

Ammonia is also formed naturally during the chemical changes that are produced in volcanic countries, through the agency of subterranean fires. It escapes often in considerable quantities from the hot lavas, and from crevices in the heated rocks.

It is produced artificially by the distillation of animal substances, (hoofs, horns, &c.,) and during the burning, coking, and distillation of coal. Soot contains much ammonia, while thousands of tons of that which is present in the ammoniacal liquors of the gas-works, and which might be beneficially applied as a manure, are annually carried down by the rivers, and lost in the sea.

Of the ammonia which is given off during the putrefaction of animal and vegetable substances, a variable proportion rises into the air, and floats in the atmosphere, 'till it is either decomposed by natural causes, or is dissolved and washed down by the rains. In the latter case it sinks into the ground, and finds its way into the roots of plants. In our climate, cultivated plants appear to derive a considerable proportion of their nitrogen from ammonia. It is one of the most valuable fertilising substances contained in farm-yard manure; and as it is usually present in greater proportion in the liquid than in the solid contents of the farm-yard, much real wealth is lost, and the means of raising increased crops thrown away, in the quantities of liquid manure which are almost everywhere permitted to run to waste.

SECTION V.—OF OTHER ORGANIC ALKALIES, AND THEIR INFLUENCE UPON VEGETATION.

Ammonia has hitherto been considered by chemists as the only organic substance of a volatile and alkaline nature, which exercised a sensible influence upon vegetation. But a number of other organic alkalies, volatile like ammonia, possessed of a powerful odour, soluble in water, and like it *containing nitrogen,* have recently been discovered. Some of these are of such a kind as to be naturally produced, I believe, during the decay and fermentation of animal and vegetable substances; and if so, they cannot fail to affect the growth of plants.

These alkaline compounds contain carbon in addition to the hydrogen and nitrogen of which ammonia consists. Hence if they exist, or are formed in the soil, they will be able to minister these three elements to the wants of the plant, and in a form of combination in which they may be more readily converted into those substances of which the parts of the plant are composed.

No experiments have yet been made upon the relations which these compounds bear to vegetable life, to fertility of soil, or to fertilising manures; but I insert these brief remarks regarding them in this place from the persuasion, that the study of these relations will afford the materials for an intricate, perhaps, but most interesting and important chapter in future histories of the phenomena of vegetation.

SECTION VI.—OF NITRIC ACID, AND ITS PRODUCTION IN THE AIR AND IN THE SOIL.

Nitric acid is a powerfully corrosive liquid, known in the shops by the familiar name of *aquafortis.* It is pre-

pared by pouring oil of vitriol (sulphuric acid) upon saltpetre, and distilling the mixture. The aquafortis of the shops is a mixture of the pure acid with water.

Pure nitric acid consists of nitrogen and oxygen only, united in the proportions of 14 of nitrogen, by weight, to 40 of oxygen. It is very remarkable that the union of these two gases, so harmless in the air, should produce the burning and corrosive compound which this acid is known to be.

It never reaches the roots or leaves of plants in this free and corrosive state. It exists and is produced in many soils, and is naturally formed in compost heaps, and in most situations where animal or vegetable matter is undergoing decay in contact with the air; but in these cases it is always found in a state of chemical combination. With potash it forms *nitrate of potash*, (saltpetre,) with soda, *nitrate of soda*, with lime, *nitrate of lime*, with magnesia, *nitrate of magnesia*, with ammonia, *nitrate of ammonia*, and so on. All these nitrates are very soluble in water, and it is generally in the state of one or other of these compounds that nitric acid exists in the soil and reaches the roots of plants.

It is well known that saltpetre—called also nitre, or nitrate of potash—is in India obtained by washing the rich alluvial soil of certain districts with water, and evaporating the clear solution to dryness. On the continent of Europe, artificial nitre-beds are formed by mixing together earthy matters of various kinds with the liquid and dung of stables, and forming the mixture into heaps, which are turned over once or twice a-year. These heaps, on washing, yield an annual crop of impure saltpetre. The soil around our dwellings, and upon which our towns and villages stand, becomes impregnated with animal matter of various kinds through defective drainage, and is thus

converted into extensive nitre-beds, in which nitric acid and nitrates are produced in great abundance. The rains that fall and sink into the soil wash these downwards into the wells, if any are near. Hence nitrates usually abound in wells which are dug within the walls of large towns; and the waters of such wells are generally unwholesome to man, though they would wonderfully nourish plants, if employed for the purposes of irrigation.*

Nitric acid is also naturally formed, and in some countries probably in large quantities, by the passage of electricity through the atmosphere. The air consists of oxygen and nitrogen *mixed* together, but when electric sparks are passsed through a quantity of air, minute portions of the two gases *unite* together chemically, so that every spark which passes forms a small quantity of nitric acid. A flash of lightning is only a large electric spark; and hence every flash that crosses the air produces along its path a sensible proportion of this acid. Where thunderstorms are frequent, much nitric acid, and probably some ammonia, are produced in this way in the air. They are washed down by the rains—in which they have frequently been detected—and thus reach the soil, where the acid combines with potash, soda, lime, &c., and produces the nitrates above mentioned.

It has long been observed that those parts of India are the most fertile in which saltpetre exists in the soil in the

* "In Leon (Nicaragua) the practice of burying in the churches has always prevailed, and is perpetuated through the influence of the priests, who derive a considerable fee from each burial. The consequence is, that the ground within and around the churches has become (if the term is admissible) saturated with the dead. The burials are made, according to the amount paid to the Church, for from ten to twenty-five years, at the end of which time *the bones with the earth around them are removed and sold to the manufacturers of nitre.*"—SQUIER'S *Nicaragua*, vol. i. p. 384.

greatest abundance. The nitrates of soda and potash have been found among ourselves, also, wonderfully to promote vegetation, when artificially applied to growing crops; and it is a matter of frequent remark, that vegetation seems to be refreshed and invigorated by the fall of a thunder-shower. There is, therefore, no reason to doubt that nitric acid is really beneficial to the general vegetation of the globe. And since vegetation is most luxuriant in those parts of the globe where thunder and lightning are most abundant, it would appear as if the natural production of this compound body in the air, to be afterwards brought to the earth by the rains, were a wise and beneficent contrivance by which the health and vigour of universal vegetation is intended to be promoted.

It is from nitric acid, thus universally produced and existing, that plants appear to derive a large—probably, taking the vegetation of the earth as a whole, the largest—proportion of their nitrogen. In all climates, they also derive a portion of this element from ammonia, and from other soluble compounds containing nitrogen; but less, probably, from these sources in tropical than in temperate climates.*

SECTION VII.—OF THE COMPOSITION OF THE ATMOSPHERE.

The air we breathe, and from which plants derive a portion of their nourishment, consists of a *mixture* of oxygen and nitrogen gases, with a minute quantity of carbonic acid, and a variable proportion of watery vapour. Every hundred gallons of *dry* air contain about 21 gallons of oxygen and 79 of nitrogen. The carbonic acid amounts only to one gallon in 2500, while the watery

* For fuller information on this point, see the Author's *Lectures on Agricultural Chemistry and Geology*, 2d edition.

vapour varies from 1 to $2\frac{1}{2}$ gallons (of steam) in 100 gallons of common air.

The oxygen of the atmosphere is necessary to the breathing of animals, to the life of plants, and to the burning of bodies in the air. The nitrogen serves principally to dilute the strength, so to speak, of the pure oxygen—in which gas, if unmixed, animals would live, and combustibles burn with too great rapidity. The small proportion of carbonic acid in the atmosphere affords an important part of their food to plants, and the watery vapour aids in keeping the surfaces of animals and plants in a moist and pliant state; while, in due season, it descends also in refreshing showers, or studs the evening leaf with sparkling dew.

There is thus in the composition of the atmosphere a beautiful adjustment to the nature and necessities of living beings. The energy of the pure oxygen is tempered, yet not too much weakened, by the admixture of nitrogen gas. The carbonic acid, which, when undiluted, is noxious, especially to animal life, is mixed with the other gases in so minute a proportion, as to be harmless to animals, while it is still beneficial to plants; and when the air is overloaded with watery vapour, it is provided that it shall descend in rain.

But the air contains besides many other substances not essential to its composition, but which exercise, nevertheless, an important influence both upon animal and vegetable life. We have already seen that nitric acid, and probably ammonia, are produced in it by the agency of electricity, and are brought down by the rains. There are continually rising into it also vapours and exhalations of various kinds from the earth's surface. The sea sends up a portion of its common salt and other constituents, and the land the numberless forms of volatile matter which

arise from decaying animal and vegetable substances, from festering marshes, from burning volcanoes, and from countless manufactories and chemical operations. As the ocean receives all that water can carry into it, so the atmosphere receives everything that the air can bear up.

And lest these ever-rising exhalations should contaminate the air, and render it unfit for the breathing of animals, the rains, as they descend, dissolve, wash out, and bring them back again to the soil. Thus they purify at once the atmosphere through which they fall, and bear refreshment to the land, and the means of fertility, whereever they come.

SECTION VIII.—OF SULPHURIC AND PHOSPHORIC ACIDS.

We have stated in a previous section that sulphuric and phosphoric acids are the chief forms in which sulphur and phosphorus respectively enter into plants.

1°. SULPHURIC ACID—known also as oil of vitriol—is a very heavy, oily-looking, sour, and corrosive liquid, which becomes hot when mixed with water, chars and blackens straw or wood when immersed in it, and is capable of dissolving many organic and inorganic substances. It is manufactured by burning sulphur in large leaden chambers, and consists of sulphur and oxygen only—combined with a little water. One pound of sulphur produces about three pounds of the strongest sulphuric acid.

This acid combines with potash, soda, lime, magnesia, and ammonia, and forms *sulphates*. These sulphates exist in the soil, and when dissolved by water are conveyed into the sap of plants, and supply the sulphur which is necessary for the formation of their growing parts.

The strong acid is now employed largely for dissolving

bones and the fossil phosphate of lime, from which the artificial manure known as *super-phosphate* of lime is manufactured. In a diluted state it has been employed with advantage as a steep for barley, and even as a manure for turnips.

2°. PHOSPHORIC ACID.—If a piece of phosphorus be kindled in the air, it burns with a brilliant flame, and gives off dense white fumes. These white fumes are phosphoric acid. They are produced by the union of the burning phosphorus with the oxygen of the atmosphere. A 100 lb. of phosphorus, when burned, form 227½ lb. of phosphoric acid.

Fig. 10.

If the experiment be performed under a glass, as in the annexed figure, the white fumes of acid will condense on the cool inside of the vessel in the form of a white powder, which speedily absorbs moisture from the air, and runs to a liquid. This acid is very sour and corrosive. It combines with potash, lime, &c., and forms *phosphates*, and in these states of combination it exists in soils and manures, and enters into plants. The bones of animals contain a large proportion of this acid, chiefly in combination with lime and magnesia.

Lucifer matches are tipped with a morsel of phosphorus, which, when rubbed, takes fire and kindles the sulphur. The white smoke given off by such a match, when first kindled, consists of phosphoric acid.

CHAPTER III.

Structure of the stem, root, and leaves of plants.—Functions of the root, the leaves, and the stem.—How plants draw their nourishment from the soil and the air.—Of the substance of plants, and the structure of the seed or grain.—Of cellulose, starch, sugar, gum, mucilage, and pectose, or pectic acid.—Of the oil or fat, wax, resin, and turpentine of plants.—Of gluten, albumen, and casein.—Germination of seeds and growth of plants.—Mutual transformations of starch, sugar, and cellulose.—Production of cellular fibre from the organic food of plants.—Necessity of nitrogen, or substances containing it, to the growth of plants.—Forms in which nitrogen may enter into plants.

FROM the compound substances described in the preceding chapter, plants derive the greater portion of the carbon, hydrogen, oxygen, and nitrogen, with the sulphur and phosphorus of which their organic part consists. The living plant possesses the power of absorbing these compound bodies, of *decomposing* them in the interior of its several vessels, and of *re-compounding* their elements in a different way, so as to produce new substances,—the ordinary products of vegetable life.

Before describing the nature of these new substances, I shall briefly consider the general structure of plants, and their mode of growth.

SECTION I.—OF THE STRUCTURE OF THE STEM, ROOT, AND LEAVES OF PLANTS.

A perfect plant consists of three several parts:—a root which throws out arms and fibres in all directions into the soil; a trunk which branches into the atmosphere on every side; and leaves which, from the ends of the

branches and twigs, spread out a more or less extended surface into the surrounding air. Each of these parts has a peculiar structure, and special functions assigned to it.

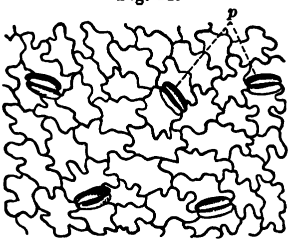
1°. The *stem* of any of our common trees consists of three parts—the pith in the centre, the wood surrounding the pith, and the bark which covers the whole. The pith consists of a collection of minute cells, supposed to communicate horizontally with the external air through the medullary rays and the outer bark; while the wood and inner bark are composed of long tubes bound together in a *vertical* position, so as to be capable of carrying liquids up and down between the roots and the leaves. When a piece of wood is sawn across, the ends of these tubes may be distinctly seen. The branch is only a prolongation of the stem, and has a similar structure.

2°. The *root*, immediately on leaving the trunk or stem, has also a similar structure. But as the root tapers away, the pith disappears—in some, as in the walnut and horse-chestnut, gradually—in others immediately. The bark also thins out, and the wood softens, till the white tendrils, of which its extremities are composed, consist only of a colourless spongy mass, full of pores, and in which no distinction of parts can be perceived. In this spongy mass the vessels or tubes which descend through the stem and root lose themselves, and by these tubes the spongy extremities in the soil are connected with the leaves in the air.

3°. The *leaf* is an expansion of the twig. The fibres, which are seen to branch out from the base through the interior of the leaf, are prolongations of the vessels of the wood, and are connected with similar prolongations of the inner bark, which usually lie beneath them. The green exterior portion of the leaf is, in like manner, a continuation of the outer or cellular tissue of the bark, in a very

thin and porous form. The pores, or mouths (*stomata*) contained in the green part, are an essential feature in the structure of the leaves, and are very numerous. The leaf of the common lilac contain as many as 120,000 of them on a square inch of surface. They are generally most numerous on the under part of the leaf, but in the case of leaves which float upon water, they are chiefly confined to the upper part.

Fig. 11.



The annexed woodcut shows the appearance of the oval pores *p* on the leaf of the garden balsam. Connected with these pores, the green part of the leaf consists of or contains a collection of tubes or vessels which stretch along the surface of the leaf, and communicate, as we have said, with those of the inner bark.

SECTION II.—FUNCTIONS OF THE ROOT, THE LEAVES, AND THE STEM.—COURSE AND MOTION OF THE SAP.

Each of these principal parts of the plant performs its peculiar functions.

1°. *Functions of the root.*—The root sends out fibres in every direction through the soil in search of water and of *liquid* food, which its spongy extremities suck in, and send forward with the sap to the upper parts of the tree. It is to aid the roots in procuring the food more rapidly that in the art of culture such substances are mixed with the soil as experience has shown to be favourable to the growth of the plants we wish to raise.

What chemical changes the food is made to undergo

in entering or passing along the roots is not yet understood.

2°. *Functions of the leaf.*—It is not so obvious to the common observer that the leaves spread out their broad surfaces into the air for the same purpose precisely as that for which the roots diffuse their fibres through the soil; the only difference is, that while the roots suck in chiefly *liquid*, the leaves inhale almost solely *gaseous* food. *In the daytime, whether in the sunshine or in the shade, the green leaves are continually absorbing carbonic acid from the air, and giving off oxygen gas.* That is to say, they are continually appropriating carbon from the air.* *When night comes, this process is reversed, and they begin to absorb oxygen and to give off carbonic acid.* But the latter process does not go on so rapidly as the former; so that, on the whole, plants, when growing, gain a large portion of carbon from the air. The actual quantity, however, varies with the season, with the climate, and with the kind of plant. The proportion of its carbon, which has been derived from the air, is greatly modified, also, by the quality of the soil in which the plant grows, and by the comparative abundance of liquid food which happens to be within reach of its roots. It has been ascertained, however, that in our climate, on an average, not less than from one-third to four-fifths of the entire quantity of carbon contained in the crops we reap from land of average fertility, is really obtained from the air.

We see then why, in artic climates, where the sun, once risen, never sets again during the entire summer, vegetation should almost rush up from the frozen soil; the green

* Since carbonic acid, as shown in the previous chapter, (p. 21,) consists only of carbon and oxygen. Of these the leaves retain the carbon and reject the oxygen.

leaf is ever gaining from the air and never losing, ever taking in and never giving off carbonic acid, since no darkness ever interrupts or suspends its labours.

How beautiful, too, does the contrivance of the expanded leaf appear! The air contains only one gallon of carbonic acid in 2500, and this proportion has been adjusted to the health and comfort of animals to whom this gas is hurtful. But to catch this minute quantity, the tree hangs out thousands of square feet of leaf—in perpetual motion, through an ever-moving air; and thus, by the conjoined labours of millions of pores, the substance of whole forests of solid wood is slowly extracted from the fleeting winds. I have already mentioned the number of pores which have been observed on a square inch of leaf; and when I add that on a single oak tree seven millions of leaves have been counted, the multitude of absorbing mouths in a forest—like those of the coralline animals in a reef—will appear equal to the most gigantic effects.

The green stem of the young shoot, and the green stalks of the grasses, also abound in pores, and consequently absorb carbonic acid, and give off oxygen, as the green leaf does; and thus a larger supply of food is afforded when the growth is most rapid, or when the short life of the annual plant demands much nourishment within a limited time. The yellow and red leaves and parts of plants give off no oxygen, (Senebier.)

3°. *Functions of the stem.*—From the spongy part of the root the sap ascends through the vessels of the woody stem till it is diffused over the interior of the leaf by the woody fibres which the leaf contains. During this passage the substances which the sap contains undergo certain chemical changes, which are as yet not well understood. From the woody fibre of the leaf—along the vessels which

lie beneath these fibres, and are covered by the green part of the leaf—and after it has absorbed or given off the gases which the pores transmit, the sap is returned towards the outer part of the stem, and through the vessels of the *inner* bark descends again to the root.

4°. *Course and motion of the sap.*—In the living plant, at least till it has passed maturity, most of the vessels are full of sap, and this sap is in continual motion upwards within the stem, and downwards along its surface within the inner bark. In spring and autumn the motion is more rapid. In winter it is sometimes scarcely perceptible; yet the sap, except when frozen, is supposed to be rarely quite stationary in any part of the tree.

SECTION III.—OF THE SUBSTANCES OF WHICH PLANTS CHIEFLY CONSIST, AND OF THE STRUCTURE OF THEIR SEEDS.

In the way above described, the perfect plant derives from the soil and from the air the food by which it is sustained and enabled to grow. In the substance or stem of plants thus formed, and in their seeds, various chemical compounds exist, but they may all be included in three main groups or classes.

When the grain of wheat, barley, oats, rye, Indian corn, &c., is sent to the mill to be ground, two products are obtained—the bran or husk, and the flour. When washed free from flour, the bran or husk is tasteless, insoluble in water, and woody. It is the same thing, indeed, for the most part, as the cellular and fibrous part of wood or straw.

Again, when a portion of the flour is made into dough, and this dough is kneaded with the hand under a stream of water upon a piece of muslin, or on a fine sieve, as long

as the water passes through milky—there will remain

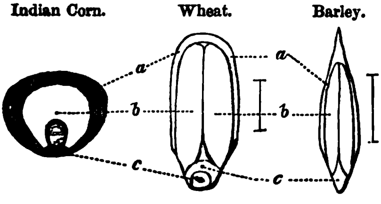
Fig. 12.

on the sieve a glutinous sticky substance resembling bird-lime, while the milky water will gradually deposit a pure white powder. This white powder is *starch*, the adhesive substance which remains on the sieve is *gluten.* Both of these substances exist, therefore, in the flour; they both also exist in the grain.

Further, when bruised wheat, oats, Indian corn, linseed, or even chopped hay and straw, are boiled in alcohol or ether, a portion of oil or fat, of wax and of resin, is extracted, and is obtained separately by allowing the solution to evaporate to dryness in the air.

Thus, from the seed or grain we have obtained four different substances—the woody part which covers it, starch, gluten, and fat. The annexed woodcut shows the position and relative quantities of the last three substances in the seeds of wheat, barley, and Indian corn.

Fig. 13.



Thus, *a* shows the position of the oil in the outer part of the seed. It exists in minute drops, enclosed in six-sided cells, which consist chiefly of gluten. *b* the position and comparative quantity of the starch, which in the heart of the seed is mixed

with only a small proportion of gluten. *c* the germ or chit which contains much gluten.

These substances represent the three great classes of organic bodies of which the bulk of all plants is made up.

The woody matter and the starch represent what is called the *starch* group. The gluten represents the *gluten* or albumen group. The oil or resin represents the *fatty* group.

I shall briefly describe these several groups or classes of substances.

SECTION IV.—OF THE STARCH GROUP—WOODY FIBRE, STARCH, GUM, MUCILAGE, SUGAR, AND PECTOSE, OR PECTIC ACID.

The *starch group* comprehends a great number of different substances, possessing different properties, but all characterised by this similarity in composition, that *they consist of carbon and water only.*

The following are the principal substances belonging to this class.

1°. *Cellulose or woody fibre.*—This forms the walls of the cells of plants, the fibres of cotton and linen, the woody part of the husk or covering of the seed, and a large portion of the substance of wood, hay, straw, &c. It is insoluble in water both in the fresh and dry states, but, as it exists in fodder, appears, after due mastication, to be in some degree soluble in the stomachs of animals. It consists of 36 parts by weight of carbon, and 45 of water.

2°. *The starches.*—There are several varieties of starch besides that which occurs in the flour of wheat, oats, barley, the potato, &c. These are all insoluble in cold water, but give a jelly with boiling water. The Iceland

moss, and some other lichens, contain a starch which gives a jelly with boiling water, but which is somewhat different from that of common starch; while the roots of the dahlia and the dandelion give a starch which dissolves in boiling water, but does not form a jelly, and falls again in a powdery state as the solution cools.

Common starch, and that of the dandelion and the lichen, consist, like woody fibre, of 36 parts of carbon by weight, and 45 of water; that of the dahlia contains a very little more water.

3°. *The gums.*—When common starch is heated in an oven to 300° F., or when it is mixed with water containing a little sulphuric acid and gently heated, it is changed into a soluble gummy adhesive substance, to which the name of Dextrin is given. In this soluble state, starch is supposed to exist abundantly in the sap of plants. The name Arabine is given to gum arabic, which is soluble in cold water, and Cerasine to cherry-tree gum, which is insoluble in cold, but dissolves readily in boiling water. All these three varieties of gum consist, like common starch and woody fibre, of 36 parts by weight of carbon, united to 45 parts of water.

4°. *The mucilages.*—The name of mucilage is given to gum tragacanth, which does not dissolve, but swells out into a jelly when placed in water—to the adhesive matter which water extracts from linseed and other oily seeds, and to the jelly which is obtained from the roots of the orchis, (Salop,) the mallow, &c. It consists of 48 parts by weight of carbon, and 57 of water.

5°. *The sugars.*—In the sap of plants several kinds of sugar occur; but those called cane and grape sugars are the most abundant.

Cane sugar exists in the sugar cane, the maple, the beet, the stalks of corn, and in many other plants. In the ordi-

nary states of loaf sugar, crystallized sugar, sugar-candy, &c., it consists of 48 parts of carbon by weight, and 66 of water.

Grape sugar exists naturally in the grape, in fruits in general, and in honey. It is formed artificially when cellulose or starch is boiled for a length of time in water made slightly sour by means of sulphuric acid, (oil of vitriol.) It is less sweet than cane sugar, and in its crystallised state consists of 48 of carbon by weight, and 84 of water.

The following table exhibits the relative composition of these several substances in a hundred parts, as nearly as it can be expressed in whole numbers :—

	Carbon.	Water.
Cellulose or woody fibre, .	44	56
Starch, ...	44	56
Gum, ...	44	56
Mucilage, . . .	46	54
Sugar of the cane, . .	42	58
Sugar of the grape, . .	36	64

In stating that these substances consist of carbon and water only, I have adopted, for the sake of clearness and simplicity, a mode of expression which has not yet been shown to be quite correct. It is not certain that these substances contain water in the proportions above stated, but they contain hydrogen and oxygen in the proportions (1 to 8) in which they form water. For simplicity, therefore, we may suppose these two elementary bodies actually to exist in the vegetable substances above described in the form of water.

6°. *Pectose and pectic acid.*—The reader will not fail to be struck with the remarkable circumstance, that substances so different as woody fibre, starch, and gum, should yet consist of the same elements—charcoal and water united together in the same proportions. In some vegetable substances, however, which otherwise resemble

starch and gum, and may be classed along with them, the hydrogen and oxygen do not exist exactly in this proportion. In fleshy fruits, such as the plum, peach, apricot, apple, pear, &c., and in the bulbs or roots of the turnip, the carrot, the parsnip, &c., there exists no starch, but in its stead a substance to which the name of pectose and sometimes of *pectic acid* is given. This substance is nearly as nutritious as starch, and serves the same purposes when eaten. It contains, however, less hydrogen and more oxygen than starch does, and changes also more readily into other substances both in the plant and in the stomach.

SECTION V.—OF THE FATTY SUBSTANCES OF PLANTS.

The fatty substances which occur in plants are of three kinds—the true fats and oils, the waxes, and the turpentines and resins. They all agree in containing less oxygen than would be required to convert their hydrogen into water—less than 8 to 1 by weight.

1°. The *true fats* which have as yet been found in plants are divided into two classes—the solid and the liquid fats.

a. Solid fats.—When almond, olive, or linseed oil is exposed to a very low temperature, a portion of it freezes or becomes solid. This portion may be separated, and by pressure may be, in great measure, freed from the liquid portion.

The solid part thus obtained from most vegetable oils is called margarine, and is identical with the solid part of butter, and of the fat of man, of the horse, and of some other animals. Some plants yield a solid fat called stearine, which is the same thing as the solid fat of the cow, the sheep, the pig, the goat, and many other animals.

b. To the *liquid* fats the name of elaine is given. That

obtained from the oils of almonds, olives, &c., which are called *fat* oils, is somewhat different from that of which linseed, walnut, and other *drying* oils chiefly consist. The liquid oil expressed from the fat of animals consists chiefly of the former variety of elaine.

2°. *The waxes.*—Many plants produce wax. It coats the flowers and leaves of many trees and shrubs, and forms the beautiful bloom which covers the grape and other fruits. From these the bees collect it; and though the different varieties of wax differ somewhat in properties, they all agree with bees-wax in being insoluble in water, partially soluble in alcohol, nearly without taste, and very combustible.

3°. The *turpentines and resins* abound in trees of the pine tribe. They are all insoluble in water, but readily soluble in alcohol; are more combustible than either true fat or wax, and contain less oxygen than either.

Nothing resembling either wax or resin is found in the bodies of animals.

SECTION VI.—OF VEGETABLE SUBSTANCES CONTAINING NITROGEN—THE GLUTEN OR ALBUMEN GROUP.

In washing the dough of wheaten flower, we have seen (p. 43) that a portion remains on the sieve or muslin, to which the name of gluten is given. This substance contains nitrogen in addition to the carbon, hydrogen, and oxygen which are present in the bodies described in the preceding sections, and is the representative of an entire class of important substances into which nitrogen enters as a constituent. I shall briefly mention the most important of these substances.

1°. *Gluten.*—This is obtained from the dough of wheaten flour, in the way already described. It is insoluble in

water, partly soluble in alcohol, which extracts from it a fatty oil, and entirely and easily soluble in vinegar, (acetic acid,) or in solutions of caustic potash, or soda. Besides the fatty oil which it contains, the crude gluten, as it is washed from wheaten flour, consists of at least two substances,—one soluble in alcohol, (*glutin*,) the other insoluble in this liquid, (gluten,) and which appears closely to resemble *coagulated albumen*. When moist, gluten is nearly colourless, and is tenacious and adhesive like bird-lime; but when perfectly dry, it is hard, brittle, and of a grey or brownish colour.

2°. *Albumen*.—The white part of eggs is called albumen by chemists. In the natural state it is a glairy thick liquid, which can be diffused through or dissolved in water, but which coagulates, or becomes solid and opaque, when heated to about 180° of Fahrenheit, or nearly to the temperature of boiling water. In this coagulated state it is insoluble in water, or in alcohol, but dissolves in vinegar, or in solutions of caustic potash or soda. When dried it becomes hard, brittle, semi-transparent, and of a brownish colour.

When the expressed juice or sap of plants is heated, a solid substance coagulates, and separates from it in opaque white flocks. This substance possesses nearly all the properties of the albumen of the egg, and is therefore called vegetable albumen.

Albumen exists in plants not only in the liquid state, as in the sap of plants, but also in the coagulated state. In the husks and envelopes of many seeds—the bran of corn for example—and in the solid parts of woody and herbaceous plants, it is found in this state in greater or less proportion.

3°. *Casein*.—When rennet, vinegar, or diluted muriatic acid is added to milk, it coagulates or curdles, and a white

curd separates from the whey. Alcohol or ether extracts the fat or butter from the coagulated mass, and leaves pure curd behind. To this curd chemists give the name of casein.

When cold water is shaken up with oatmeal for half an hour, and is then allowed to subside, the clear liquid becomes troubled on the addition of a little acid, and a white powder falls, possessing nearly all the properties of the casein of milk.

The sap of nearly all plants—the expressed juice of the potato, the turnip, and other roots, after being heated to coagulate the albumen—and the solution obtained when the meal of the bean, the pea, and other legumes, is treated with warm water—yield, on the addition of an acid, precipitates of this substance differing but little from one another.

Vegetable casein, therefore, is a constant constituent of our best known and cultivated plants. To the variety obtained from the oat the name of *avenin* has been given; and to that yielded by the bean, the pea, and the vetch, the name of *legumin*.

All these substances are combinations of a body called *protein*, and are therefore frequently spoken of under the general designation of *protein compounds*.* They occur mixed in variable proportions in the different kinds of grain and roots which are used for food. In addition to carbon, oxygen, and hydrogen, they all contain, when quite dry, about 16 per cent of nitrogen, with 1 or 2 per cent of sulphur, and most of them also a small per-centage of phosphorus.

* For an account of protein and its compounds, see my *Lectures on Agricultural Chemistry*, 2d edition, p. 15.

SECTION VII.—OF THE GERMINATION OF SEEDS AND THE GROWTH OF PLANTS.

When a seed is committed to the earth, if the warmth and moisture are favourable, it begins to sprout. It pushes a shoot upwards, it thrusts a root downwards, but, until the leaf expands, and the root has fairly entered the soil, the young plant derives no nourishment other than water, either from the earth or from the air. It lives on the starch and gluten contained in the seed. But these substances, though capable of being separated from each other by means of water, as described in a previous section, (p. 43,) are neither of them soluble in water. Hence they cannot, without undergoing a previous chemical change, be taken up into the sap and conveyed along the vessels of the young shoot they are destined to feed. But it is so arranged in nature that, when the seed first sprouts, there is produced at the base of the germ, from a portion of the gluten, a small quantity of a white soluble substance called *diastase*. This substance exercises so powerful an effect upon the starch as almost immediately to render it soluble in the sap, which is thus enabled to take it up and convey it by degrees, just as it is wanted, to the shoot or to the root.* The starch, when thus changed and rendered soluble,

* In malting barley, it is made to sprout a certain length, and the growth is then arrested by heating and drying it. Mashed barley, before sprouting, will not dissolve in water; but when sprouted, the whole of the starch (the flour) it contains dissolves readily by a gentle heat, and is changed into soluble *dextrin*. The *diastase* formed during the germination effects this. By further heating in the brewer's wort, this dextrin is converted into sugar by the agency of the same diastase, as it is also in the growing plant. We can thus imitate by art; and, in brewing, we do imitate what takes place naturally in the living vegetable.

becomes the substance called *dextrin*, which we have already described, (p. 45.)

In the oily seeds which contain no starch, the mucilage and the oil take the place of starch in nourishing the young sprout.

As the sap ascends it becomes sweet—the dextrin formed from the starch is further changed into sugar. When the shoot first becomes tipped with green, this sugar again is changed into cellulose or woody fibre, of which the stem of perfect plants chiefly consists. By the time that the food contained in the seed is exhausted—often long before—the plant is able to live by its own exertions, at the expense of the air and the soil.

This change of the sugar of the sap into cellular or woody fibre is observable more or less in all plants. When they are shooting fastest the sugar is most abundant—not, however, in those parts which are actually shooting up, but in those which convey the sap to the growing parts. Thus the sugar of the ascending sap of the maple and the alder disappears in the leaf and in the extremities of the twig. Thus the sugar-cane *sweetens* only a certain distance above the ground, up to where the new growth is proceeding; and thus also the *young* beet and turnip abound most in sugar—while in all these plants the sweet principle diminishes as the year's growth draws nearer to a close.

In the ripening of the ear, also, the sweet taste at first so perceptible in young grain gradually diminishes, and finally disappears. The sugar of the sap is here changed into the *starch* of the grain, which, as above described, is afterwards destined, when the grain begins to sprout, to be reconverted into sugar for the nourishment of the rising germ.

In the ripening of fruits a different series of changes

presents itself. The fruit is at first tasteless, then becomes sour, and at last sweet. In this case, either the acid of the unripe is changed into the sugar of the ripened fruit, or a portion of the other constituents of the fruit—its cellulose and pectose—are converted into sugar, and disguise the acid.

SECTION VIII.—HOW THE CELLULAR OR WOODY MATTER OF PLANTS IS FORMED FROM THEIR ORGANIC FOOD.

The substance of plants—their solid parts, that is—consists chiefly, as we have already stated, of *cellular fibre*, the name given to the fibrous substance of which wood evidently consists. It is interesting to inquire how this substance can be formed from the compounds—water and carbonic, humic, ulmic, and other acids—of which the organic food of plants in a great measure consists. Nor is it difficult to find an answer.

1°. It will be recollected that the leaf drinks in carbonic acid from the air, and delivers back its oxygen, retaining only its carbon, (p. 40.) It is also known that water abounds in the sap. Hence carbon and water are abundantly present in the pores or vessels of the green and living leaf. Now, as cellulose or woody fibre *consists only of carbon and water* chemically combined together, it is easy to see how, when the carbon and water meet in the leaf, cellular fibre may be produced by their mutual combination.

2°. If, again, we inquire how this important constituent of plants may be formed from the other substances, which enter by their roots—from the humic acid (p. 21) for example—the answer is equally ready. This acid also consists of carbon and water only—50 lb. of carbon with $37\frac{1}{2}$ of water forming $87\frac{1}{2}$ of humic acid—so that, when it is conveyed by the roots into the sap of the plant, all the

materials are present from which the cellular fibre may be produced.

3°. Nor is it more difficult to understand how the starch of the seed may be converted into sugar, and this again into cellular fibre; or how, conversely, sugar may be changed into starch in the ear of corn, or cellular fibre into sugar during the ripening of the winter pear after its removal from the tree. *Any one of these substances may be represented by carbon and water only.* In the interior of the plant, therefore, it is obvious that if any one of them is present in the sap, the elements are at hand out of which any of the others may be produced. In what way they really are produced, the one from the other, and by what circumstances these transformations are favoured, it would lead into too great detail to attempt here to explain.*

We cannot help admiring the varied purposes to which in nature the same elements are applied,—and from how small a number of materials, substances the most varied in their properties are in the living vegetable daily produced.

SECTION IX.—OF THE NECESSITY OF NITROGEN, OR OF SUBSTANCES CONTAINING IT, TO THE GROWTH OF THE PLANT, AND OF THE FORMS IN WHICH IT MAY ENTER THE ROOTS.

But a substance containing nitrogen is necessary to the production of those beautiful and varied changes which take place in the sap of the plant at the different stages of its growth.

* For fuller and more precise explanations on these interesting topics, see the Author's *Lectures on Agricultural Chemistry and Geology*, 2d edition, Part I.

We have seen that, during germination, the insoluble gluten of the seed is partly changed into a soluble substance—diastase—by which the first alteration of the insoluble starch into soluble dextrin is effected. The remainder of the gluten ascends or descends by degrees with the sap, in some soluble form which is not yet clearly understood, and, if not actually the cause of the successive changes which the starch, sugar, and gum of the sap undergo, it is at least always present when they are produced.

At every point in the growing shoot and root some compound of nitrogen must be present, if it is to increase in size,—since in the interior of every new cell the presence of such a compound in minute quantity can be distinctly recognised. In the young radicles of the sprouting barley there are 32 per cent of a substance containing nitrogen, while the grain itself contains only 14. This substance seems to preside over the change of the soluble substances contained in the sap, into the insoluble fibre of the cell. The change of the sugar and gum of the sap into the starch of the ear always takes place also in the presence of a substance containing nitrogen. In the young seed it is present in much larger proportion than when the seed is matured. In the pea, when beginning to form in the shell, it constitutes 48 per cent of the whole weight, (Payen,) while in the ripe pea it does not exceed one-half the quantity.

When the starch or sugar undergoes a change, the nitrogenous compound undergoes a simultaneous change; and as the transformation of the starch of the seed into the sugar of the sap is attended by the change of its gluten into diastase and other soluble compounds, so the converse change of the sugar of the sap into the starch of the ear is attended by a converse production of the insoluble gluten of the ripening grain.

It has also been ascertained that the leaves of growing plants are in the sunshine always giving off nitrogen, in quantity which varies with the kind, and probably the age, of the plant, and with the time during which it has been exposed to the sun's rays. This nitrogen appears to be derived from gluten and other nitrogenous (protein) compounds, which are continually undergoing changes in the sap, and which are necessary to the ordinary processes of vegetable growth.

The necessity of nitrogen to the growth of the plant in all its stages is thus fully established; and hence the utility, established by long practical experience, of applying manures in which nitrogen is contained.

It has not yet been proved in what form of combination nitrogen is *most fitted* to promote the growth of our cultivated crops. It usually finds its way into the roots of plants in the form of nitric acid, of ammonia, of other organic alkalies containing nitrogen, (p. 31,) or of the compounds of these alkalies with the humic and ulmic acids, which are so extensively produced in the soil itself. Animal manures may owe part of their peculiar beneficial action to their supplying other compounds of nitrogen—protein compounds, perhaps, in a soluble form—which the plant, with still less trouble to itself, can convert into portions of its own substance.

The plant grows rapidly by the aid of the ready-formed gluten of the seed,—why should it not thrive well also by the aid of similar compounds placed within its reach in the soil and absorbed by its roots? There seems, indeed, very little solid foundation for the opinion held by some, that the plants *in our cultivated fields* derive the *whole* of their nitrogen from ammonia and nitric acid together—still less that they obtain it from ammonia alone.

The plant that grows on the surface of common vine-

gar, and makes it thick and glairy, is formed from the vinegar* itself, and from a nitrogenous substance resembling gluten, which the liquid vinegar holds in solution. So the mould which grows on flour paste is formed from the starch and the gluten of the flour, and the minute plant which forms the yeast in the brewer's vat is produced from the sugar of the wort and the changed gluten of the barley.

In all these cases the substance of the plant is formed by the direct appropriation of compounds, which bear a close analogy to those of which its own parts consist; and though the mould plants above mentioned are very different in kind from those we raise for food, yet the mode in which they are built up is very similar to that by which the solid parts of larger plants are really produced from the substances contained in the sap. If, then, those substances from which their growing parts are thus known to be built up can be conveyed directly into the circulation of our cultivated plants by their roots, it is reasonable to suppose that their growth may be promoted by *them* at least as well as if the roots took up only carbonic acid to supply the carbon, and ammonia to supply the nitrogen.

In other words, the probabilities are, I think, in favour of the view that animal or vegetable substances containing nitrogen, when brought into a soluble state by fermentation, may enter directly into the roots, and feed our crops, without being first *decomposed* either into ammonia or into nitric acid. The subject is deserving, therefore, of being made matter of direct experiment in the field or garden.

* Pure vinegar, like starch and cellular fibre, consists of carbon and water alone, 50 of carbon and 56 of water forming 106 of vinegar.

CHAPTER IV.

Of the inorganic constituents of plants.—Potash, soda, lime, magnesia, silica, alumina, oxide of iron, oxide of manganese, sulphur, sulphuric acid, phosphorus, phosphoric acid, chlorine, iodine, fluorine.—Immediate source of these constituents of plants.—The quantity contained in plants, and in parts of plants, varies with many circumstances.—The composition or quality of the inorganic constituents in plants.—It varies also with many circumstances.—Average quantity of each constituent in certain common crops, and in a series of crops.—Practical deductions from a knowledge of the inorganic constituents of plants.

SECTION I.—SOURCE OF THE EARTHY MATTER OF PLANTS, AND SUBSTANCES OF WHICH IT CONSISTS.

When plants are burned, they always leave more or less of ash behind. This ash varies in quantity in different plants, in different parts of the same plant, in different specimens even of the same kind, and of the same part of a plant, especially if grown upon different soils; yet it is never wholly absent.* It is as necessary to their existence in a state of perfect health, as any of the elements which constitute the organic or combustible part of their substance. They must obtain it, therefore, along with the food on which they live. It is, in fact, a part of their natural food, since without it they become unhealthy. We shall speak of it, therefore, as the *inorganic food* of plants.

We have seen that all the elements which are necessary

* The only known exceptions occur in the mould plants—as in the *mycoderma vini*, which grows on pure vinegar, that which grows on solutions of milk sugar, &c. By these no trace of ash is left.

to the production of the cellular fibre, and of the other organic parts of the plant, may be derived either from the air, from the carbonic acid and watery vapour taken in by the leaves, or from the soil through the medium of the roots. In the air, however, only rare particles of inorganic or earthy matter are known to float, and these are in a solid form, and therefore unable to enter the minute pores of the leaves. Hence the earthy matter which constitutes the ash of plants must all be derived from the soil.

The earthy part of the soil, therefore, serves a double use. It is not, as some have supposed, a mere substratum, in which the plant may so fix and root itself as to be able to maintain its upright position against the force of winds and tempests; but it is a storehouse of food also, from which the roots of the plant may select such earthy substances as are necessary to, or are fitted to promote, its growth.

The ash of plants consists of a mixture of several, sometimes of as many as fourteen, different substances. These substances are the following:—

1. *Potash.*—The common pearl-ash of the shops is a compound of potash with carbonic acid, or it is a *carbonate of potash*. By dissolving the pearl-ash in water, and boiling it with quicklime, the carbonic acid is separated, and potash alone, or caustic potash, as it is often called, is obtained.

2. *Soda.*—The common soda of the shops is a *carbonate of soda*. By boiling it with quick-lime, the carbonic acid is separated, as in the case of pearl-ash, and pure or caustic soda remains. The proportions to be used are 1 lb. of the carbonate to a ½ lb. of lime and 10 lb. of water.

3. *Lime.*—This is familiar to every one as the *lime-shells*, or unslaked lime of the lime-kilns. The unburned lime-

stone is a *carbonate of lime*, the carbonic acid in this case being separated from the lime by the roasting in the kiln.

4. *Magnesia*.—This is the calcined magnesia of the shops. The uncalcined is a *carbonate of magnesia*, from which heat drives off the carbonic acid.

5. *Silica*.—This is the name given by chemists to the substance of flint, of quartz, of rock crystal, and of siliceous sands and sandstones. It is particularly abundant in the straws and grasses, and in the glaze of the bamboo and other canes.

6. *Alumina* is the pure earth of alum, obtained by dissolving alum in water, and adding liquid ammonia (hartshorn) to the solution. It forms about two-fifths of the weight of porcelain and pipe-clays, and of some other *very* stiff kinds of clay. It exists abundantly in most soils, but as an essential constituent of plants it has hitherto been met with only in the ash of the club mosses.

7. *Oxide of iron*.—The most familiar form of this substance is the rust that forms on metallic iron in damp places. It is a compound of iron with oxygen, hence the name *oxide*.

There are, however, two oxides of iron. The *red*, which gives its colour to rust and to our red soils. This oxide is insoluble in water, and has the property of absorbing ammonia to a certain extent.

The *black* oxide gives their colour to many blue clays. It is soluble in weak acids, is produced from the red oxide by the action of organic matter in the soil, and is believed, when so produced, to be very noxious to the roots of plants.

8. *Oxide of manganese* is a dark brown powder, which consists of oxygen in combination with a metal resembling iron, to which the name of manganese is given. It

usually exists in plants and soils in very small quantity only.

9. *Sulphur.*—This substance is well known. It is present in nearly all the parts of plants and animals. It exists largely in mustard seed, is a necessary constituent of the gluten of wheat, of the white of the egg, of the fibre of beef, and of the curd of milk, and forms one-twentieth part of the weight of hair and wool. When sown along with turnip seed, it is said to prevent the attack of the fly.

Sulphuric Acid, or oil of vitriol, has been already described. It forms, with potash, *sulphate of potash;* with soda, *sulphate of soda,* or Glauber's salts; with ammonia, *sulphate of ammonia;* with lime, *sulphate of lime* or gypsum; with magnesia, *sulphate of magnesia,* or Epsom salts; with alumina, *sulphate of alumina,* which exists in alum; and with oxide of iron, *sulphate of iron,* or green vitriol. When the sulphate of potash is combined with sulphate of alumina, it forms common alum.

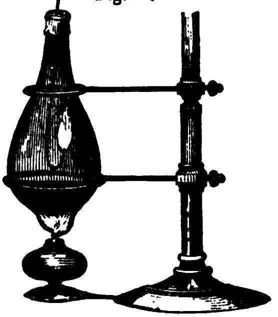
10. *Phosphorus and phosphoric acid* have been already described, (pp. 10 and 35.)

Phosphoric acid forms *phosphates* with potash, soda, ammonia, lime, and magnesia. When bones are burned, a large quantity of a white earth remains, (bone earth,) which is chiefly a *phosphate of lime,* consisting of lime and phosphoric acid, in the proportion of 48½ of phosphoric acid to 51½ of lime. Phosphate of lime is present in the ash of plants generally. Phosphate of magnesia is contained most abundantly in the ash of wheat, barley, and other varieties of grain. It exists also in beer, to the amount sometimes of 100 grains in a gallon.

11. *Chlorine.*—This is a very suffocating gas, of a pale, yellowish green colour, which gives its peculiar smell to chloride of lime, and is used for bleaching and disinfecting

purposes. It is readily obtained by pouring muriatic acid (spirit of salt) upon the black oxide of manganese of the shops, contained in a flask, and applying a gentle heat, as in the annexed figure.

Fig. 14.



If the flask be of colourless glass, the colour of the gas will immediately become perceptible, and its smell will diffuse itself through the room. This gas is $2\frac{1}{2}$ times heavier than common air, and a burning taper plunged into it is speedily extinguished. In combination with the metallic bases of potash, soda, lime, and magnesia, it forms the *chlorides* of potassium, sodium, (common salt,) calcium, and magnesium; * and in one or other of these states it generally enters into the roots of plants, and exists in their ash.

Iodine is a solid substance of a grey colour and metallic lustre, very much resembling filings of lead. It has a peculiar odour, not unlike that of chlorine, an acrid taste, and stains the fingers of a brown colour. It is distinguished by two properties—by being changed into a beautiful violet vapour when heated, and by giving with starch a beautiful blue compound. It occurs in small quantities in sea water, and in marine and many fresh-water plants. In still smaller proportion, it has been recently detected in wood ashes and in those of

* Potash, soda, lime, and magnesia, are compounds of the metals here named with oxygen. It is a very striking fact, that the suffocating gas chlorine, when combined with sodium, a metal which takes fire when placed upon hot water, should form the agreeable and necessary condiment *common salt*.

land plants, and it probably forms a constant though very minute constituent of all the plants we raise for food.

Like their chlorine, they will obtain it generally from the soil through their roots, though, as it has been detected in the atmosphere, they may derive some of this element from the rain water that falls on their leaves.

Bromine is a dark brownish red heavy liquid, possessed of a strong odour, giving a yellowish red vapour, and colouring starch yellow. It also exists in sea water, in certain salt springs, and has been detected in the ashes of certain plants. It probably accompanies chlorine and iodine into all plants, though the proportion, which is still less than that of iodine, has hitherto prevented its presence from being detected.

As *chlorine* forms *chlorides*, so *iodine* forms *iodides*, and *bromine* forms *bromides* with the metals already mentioned. The chlorine is the only one of these three, the presence of which in plants is at present believed to be of any importance in a practical point of view.

Fluorine is a very corrosive gas, of which little is yet known. It exists in small quantity in the teeth and bones, and in the blood and milk, of animals. Traces of it also have been detected in the ashes of some plants; so that it is probably necessary to the growth of both animals and vegetables. With metals, it forms *fluorides;* and fluoride of calcium, or flour spar, is the best known and most common of its combinations.

Such are the inorganic substances usually found mixed or combined together in the ash of plants. It has already been observed, that the quantity of ash left by a given weight of vegetable matter varies with a great many conditions. This fact deserves a more attentive consideration.

SECTION II.—OF THE DIFFERENCES IN THE QUANTITY OF ASH LEFT BY PLANTS, AND BY THEIR SEVERAL PARTS.

1. The quantity of ash yielded by *different plants* is unlike. Thus 1000 lb. of the following vegetable substances, in their *ordinary* state of dryness, leave of ash, on an average,

Wheat, about	20 lb.	Wheat straw,	50 lb.
Barley, .	30	Barley straw,	50
Oats, .	40	Oat straw,	60
Rye, .	20	Rye straw,	40
Indian corn,	15	Indian corn do.	50
Beans, .	30	Pea straw,	50
Peas, .	30		

Meadow hay, . .	50 to 100 lb.
Clover hay, . .	90
Rye-grass hay, .	95
Potatoes, . .	8 to 15
Turnips, . .	5 to 8
Carrots, . .	15 to 20*

So that the quantity of inorganic food required by different vegetables is greater or less according to their nature ; and if a soil be of such a kind that it can yield only a small quantity of this inorganic food, then those plants only will grow well upon it to which this small supply will prove sufficient. Hence trees may often grow where arable crops fail to thrive, because many of the former require and contain comparatively little inorganic matter. Thus the weight of ash left by 1000 lb. of

Elm wood is	19 lb.	Birch wood is	3½ lb.
Poplar, .	20	Pine, .	1½ to 3
Willow, .	4½	Oak, .	2
Beech, .	1½ to 6	Ash, .	1 to 6

The elm and the poplar contain about as much inorganic matter as the grain of wheat, but very much less

* See *Lectures on Agricultural Chemistry and Geology*, 2d edit. p. 926.

than any of the straws or grasses. How much less also does the oak contain than either the elm or the poplar!

2. The quantity of inorganic matter varies in *different parts of the same plant.* This is shown clearly by the different proportions of ash left by the grain and by the straw of our cultivated crops, as given in the preceding table. It appears, also, by the following comparison of the quantities left by 1000 lb. of the different parts of some of our cultivated plants in their dry state. Thus—

	Roots or tuber.	Grain or seed.	Straw or stalks.	Leaves.
Turnip, .	80 lb.	25 lb.	... lb.	130 lb.
Potato, .	40 „	...	...	180 „
Wheat, .	...	20 „	50 „	...
Pea, . .	...	30 „	50 „	130 „
Tobacco, .	70 „	40 „	100 „	230 „

In trees, also, the leaves contain a much larger proportion of inorganic matter than the wood. Thus, 1000 lb. of the dry wood and leaves of the following trees left of ash respectively—

	Wood.	Leaves.	Seed.
Willow, . .	$4\frac{1}{2}$ lb.	82 lb.	...
Beech, . .	4 „	42 „	...
Birch, . .	$3\frac{1}{2}$ „	50 „	...
Pine, . .	3 „	20 to 30	50 lb.
Elm, . .	19 „	120	...

It appears, therefore, that by far the largest proportion of the inorganic matter which is withdrawn from the soil by a crop of corn is returned to it again, by the skilful husbandman, in the fermented straw. In the same way also nature, in causing the trees periodically to shed their leaves, returns with them to the soil a very large portion of the soluble inorganic substances which had been drawn from it by their roots during the season of growth.

Thus an annual top-dressing is naturally given to the land where forests grow; and that which the roots from spring to autumn are continually sucking up, and care-

fully collecting from considerable depths, winter strews again on the surface in the form of decaying leaves, so as, in the lapse of time, to form a rich and fertile soil. Such a soil must be propitious to vegetable growth, since it contains or is made up of those very materials of which the inorganic substance of former races of vegetables had been almost entirely composed.

3. It varies in quantity *in different portions of the same part of the plant.* Thus, if a tall stalk of wheat, oats, or barley straw be cut into four equal parts, and these be burned separately, the lowest portion will generally leave the smallest, the highest portion the greatest, per-centage of ash. If the bottom of the stalk, for example, leave 3½ or 4 per cent, the next portion will leave 5 or 6, the third 6 or 7, and the highest perhaps 8 or 9. This is a very interesting and curious fact, not hitherto noticed by experimenters, though evidently of great interest in connection with the inorganic food of plants.

In some cases this difference is not observed, while in others the largest proportion of ash is left by the bottom part of the straw. These exceptions, however, occur generally in stunted grain, which has grown upon an unfavourable soil, or has been injured by the season.

4. The quantity of inorganic matter often differs in *different specimens and varieties of the same plant.* Thus 1000 lb. of wheat straw, grown at different places, gave to four different experimenters 43, 44, 35, and 155 lb. of ash respectively. Wheat straw, therefore, does not always leave the same quantity of ash. The same is true also of other kinds of vegetable produce.

This fact, as well as the variation of the quantity of ash with the part of the plant, is shown by the following table of the proportions of ash left by the several parts of

two different varieties of oats grown on different soils, (Norton)—

	Hopeton oat.	Potato oat.
Grain, ...	2.14	2.22
Husk, ...	6.47	6.99
Straw, ...	4.98	8.62
Leaf, ...	8.44	14.59
Chaff, ...	16.53	18.59

Here not only do the different parts of the same plant, but similar parts also of different plants of the same species, leave very different proportions of ash.

To what is this difference owing? Is it to the nature of the soil, or does it depend upon the *variety* of wheat, oats, or other produce experimented upon? It seems to depend partly upon both.

a. Variety.—Thus, on the same field, in Ravensworth Dale, Yorkshire, on a rich clay soil abounding in lime, the *Golden Kent* and *Flanders Red* wheats were sown in the spring of 1841. The former gave an excellent crop, while the latter was a total failure, the ear containing 20 or 30 grains only of poor wheat. The straw of the former left 165 lb. of ash from 1000 lb., that of the latter only 120 lb. *Something, therefore, depends upon the variety.*

b. Soil.—Again, 1000 lb. of the straw of the same variety of oat, grown by the Messrs Drummond of Stirling in 1841, upon

Aberdeen granite, left	96 lb.	of ash.
On clay-slate, .	78	...
On greenstone, .	79	...
On limestone, .	102	...
On gypsum, .	58	...
On silicious sand,	64	...
On light loamy soil,	88	...

The quantity of ash, therefore, depends in some measure also upon the nature of the soil.

5. *But the degree of ripeness* which a plant has attained

has also an influence on the proportion of ash which it leaves. Thus the straw of the same wheat grown on the same limestone soil near Wetherby, in Yorkshire, gave me, when cut five weeks before it was ripe, 40 lb., and when fully ripe, 55 lb., from 1000 lb. of dry straw. To compare the ash, therefore, of any two samples of straw, they ought to be gathered in the same state of ripeness.

A similar observation also has been made in regard to the wood of trees. The quantity of ash they leave varies both with their age and with the season of the year at which they are burned.

On the whole, the truth, so far as it can as yet be made out, seems to be this—that every plant must have a certain quantity of inorganic matter to make it grow in the *most healthy* manner—that it is capable of living, growing, and even ripening seed with much less, and probably with much more, than this quantity—but that those soils will produce the most perfect plants which can best supply all their wants; and that the best seed will be raised in those districts where the soil, without being too rich or rank, yet can yield both organic and inorganic food in such proportions as to maintain the corn plants in their most healthy condition.

This latter observation, in regard to the quality of seed, is of great practical importance, and must be borne in mind when we come hereafter to inquire whether seeds can be so prepared or doctored, by steeping or otherwise, as to grow quicker, with more certainty, and with greater luxuriance, and to yield larger returns of grain.

SECTION III.—OF THE COMPOSITION OR QUALITY OF THE ASH OF PLANTS, AND THE CIRCUMSTANCES BY WHICH IT IS MODIFIED.

But much also depends upon the *quality* as well as upon the *quantity* of the ash. Plants may leave the same weight of ash when burned, and yet the nature of the specimens of ash — the kind of matter of which they respectively consist—may be very different. The ash of one may contain much lime, of another much potash, of a third much soda, while in a fourth much silica may be present. Thus 100 lb. of the ash of *bean* straw have been found to contain 53 lb. of potash, while that of *barley* contained only 9 lb. in the hundred. On the other hand, 100 lb. of the ash of barley straw contain 68 lb. of silica, while in that of bean straw there are only 7 lb.

The quality of the ash seems to vary with the same conditions by which its quantity is affected. Thus—

1. *It varies with the kind of plant.*—1000 lb. of the ash of the *grain* of wheat, barley, oats, beans, and linseed—of the potato tuber and the turnip bulb, for example—contain respectively—

	Wheat.	Barley.	Oats.	Rye.	Indian corn.	Beans.	Linseed.	Potato.	Turnip.
Potash, . .	237	136	262	220	325 (Potash and Soda)	336	245	557	419
Soda, . .	91	81	...	116		106	34	19	51
Lime, . .	28	26	60	49	14	58	147	20	136
Magnesia, .	120	75	100	103	162	80	99	53	53
Oxide of iron, .	7	15	4	13	3	6	19	5	13
Phosphoric acid,	500	390	438	495	449	380	381	126	76
Sulphuric acid,	3	1	105	9	28	10	9	136	136
Silica, . .	12	273	27	4	14	12	57	42	79
Chlorine, . .	...	trace.	3	...	2	7	3	42	36
	998	997	999	1009	997	995	994	1000	999

A comparison of the numbers in the first four columns shows how unlike the quantities of the different substances are which are contained in an equal weight of the ash of the four varieties of grain. It is to be remarked, however, that the great difference in the case of barley arises from the thick husk with which it is covered, and from which the large per-centage of silica is derived. The sample of oats was taken without the husk.

Beans contain more sulphuric acid, also, than any of the other grains in the above table, while they are deficient in phosphoric acid when compared with wheat, barley, or oats. But the most striking differences appear between the several kinds of grain and the potato and turnip. In these last the alkaline matter is very much greater, while the phosphoric acid is much diminished.

It is thus evident that a crop of wheat will carry off from the soil—even suppose the whole *quantity* of ash left by each to be the same in weight—very different quantities of potash, soda, lime, phosphoric acid, &c., from what would be carried off by a crop of beans or of potatoes. It will, therefore, exhaust the soil more of *some*, as beans and potatoes will of *other* substances. Hence *one* reason why a piece of land may suit one crop and not suit another. Hence, also, two successive crops of *different* kinds may grow well where it would greatly injure the soil to take two in succession of the *same* kind, especially of either wheat or barley; and hence we likewise deduce one natural reason for a rotation of crops. The surface-soil may be so far exhausted of one inorganic substance that it cannot afford it in sufficient quantity to bring a given crop to healthy maturity; and yet this substance may, by natural processes, be so far restored again, during the intermediate growth of certain other crops, as to be prepared in a future season fully to supply

all the wants of the same crop, and to yield a plentiful harvest.

2. *The kind of inorganic matter varies with the part of the plant.*—Thus the grain and the straw of the corn-plants contain very unlike quantities of the several inorganic constituents, as will appear by comparing the several columns in the following with those of the preceding table.

1000 lb. of the ash of the *straw* of wheat, barley, oats, rye, and Indian corn, have been found to contain respectively of—

	Wheat.	Barley.	Oats.	Rye.	Indian corn.
Potash,	125	92	191	173	96
Soda,	2	3	97	3	286
Lime,	67	85	81	90	83
Magnesia,	39	50	38	24	66
Oxide of iron,	13	10	18	14	8
Phosphoric acid,	31	31	26	38	171
Sulphuric acid,	58	10	33	8	7
Chlorine,	11	6	32	5	15
Silica,	654	676	484	645	270
	1000	963	1000	1000	1012

The quantities of the several inorganic substances contained in the above kinds of straw are very different from those contained in the corresponding kinds of grain. In this difference we see *one* reason why the same soil which may be favourable to the growth of the straw of the corn plant may not be equally propitious to the growth of the ear. The straw contains comparatively little of some of the ingredients found in the ear, especially of the lime, magnesia, and phosphoric acid, while the grain contains a large proportion of these substances. On the other hand, the straw is rich, and the grain very poor in silica.

It is clear, therefore, that the roots may, in certain plants and in certain soils, succeed in fully nourishing the straw while they cannot fully ripen the ear; or contrariwise, where they feed but a scanty straw, may yet *be able* to give ample sustenance to the filling ear.*

That similar differences prevail in other orders of plants also, and that their several parts require, therefore, different proportions of the several kinds of inorganic food to bring them to perfection, is shown by the following table.

1000 lb. of the ash of the stem, leaves, and fruit of the apple tree, (*Pyrus spectabilis*—Chinese crab,) have been found to contain respectively, (Vogel,)

	Stem.	Leaves.	Fruit.
Carbonates of potash and soda, .	46	68	190
Phosphates of do., ...	...	trace.	141
Carbonate of lime, ...	822	729	370
Carbonate of magnesia, ...	49	98	55
Phosphates of lime and magnesia, .	88	105	186
Silica, ...	...	...	37
	1005	1000	979

Thus potash and phosphoric acid abound most in the fruit of the apple tree, as they do in the ear of our corn plants, and are therefore as necessary to their healthy growth and complete maturity.

3. *The quality of the ash varies also with the kind of soil in which the plant is made to grow.*—This will be understood from what has been stated above. Where the soil is favourable, the roots can send up into the straw everything which the plant requires for its healthy growth, and in the right proportions. When it is either too

* And occasionally do give; for a plump grain, and even a well-filled ear, are not unfrequently found where the straw is unusually deficient.

poorly or too richly supplied with one or more of those inorganic constituents which the plant desires, life may indeed be prolonged, but a stunted or unhealthy crop will be raised, and the kind, and perhaps the quantity, of ash left on burning it, will necessarily be different from that left by the same species of plant grown under more favouring circumstances. Of this fact there can be no doubt, though the extent to which such variations may take place without absolutely killing the plant has not yet been made out. That it is considerable is shown by the following table, which exhibits the composition of 1000 lb. of the ash of three samples of wheat grown in different localities:—

	Dutch.	German.	
		White.	Red.
Potash,	64	219	338
Soda,	278	157	...
Lime,	39	19	31
Magnesia,	130	96	136
Oxide of iron,	5	14	3
Sulphuric acid,	3	2	...
Phosphoric acid,	461	493	492
Silica,	3	...	...
	983	1000	1000

In the first of these we find little potash, in the last no soda, while in all nearly half the weight consists of phosphoric acid.

4. *It varies also with the period of a plant's growth, or the season at which it is reaped.*—Thus, in the young leaf of the turnip and potato, a greater proportion of the inorganic matter consists of potash than in the old leaf. The same is true of the stalk of wheat; and similar differences

prevail in almost every kind of plant at different stages of its growth.

The enlightened agriculturist will perceive that all the facts above stated have a more or less obvious connection with the ordinary processes of practical agriculture, and tend to throw considerable light on some of the principles by which these processes ought to be regulated. One illustration of this is exhibited in the following section.

SECTION IV.—AVERAGE QUANTITY OF INORGANIC MATTER CONTAINED IN AN ORDINARY CROP, OR SERIES OF CROPS.

The importance of the inorganic matter contained in living vegetables, or in vegetable substances when reaped and dry, will appear more distinctly if we consider the actual quantity carried off from the soil in a series of crops.

In a four years' course of cropping, in which the crops gathered amount per acre to—

1st year, *Turnips*, 20 tons of bulbs and 6⅓ tons of tops.
2d year, *Barley*, 40 bushels of 63 lb. each, and 1 ton of straw.
3d year, *Clover and Rye-Grass*, 1½ ton of each in hay.
4th year, *Wheat*, 25 bushels of 60 lb., and 1¾ tons of straw.

1°. The quantity of inorganic matter carried off in the four crops, supposing none of them to be eaten on the land, amounts to about—

Potash,	317 lb.	Sulphuric acid,	108 lb.
Soda,	54 „	Phosphoric acid,	116 „
Lime,	193 „	Chlorine,	70 „
Magnesia,	55 „		
Oxide of iron,	15 „		
Silica,	356 „	Total,	1284 „

or in all about 11 cwt.; of which gross weight the different substances form very unlike proportions.

2°. A still clearer view of these quantities will be obtained by a consideration of the fact, that if we carry off the entire produce, and add none of it again in the shape of manure, we must or ought, in its stead, if the land is to be restored to its original condition, to add to each acre every four years—

Dry pearl-ash,	465	lb.
Common bone dust,	552	„
Epsom salts,	326	„
Common-salt,	116	„
Quick-lime,	70	„
Total,	1529	„

Several observations suggest themselves from a consideration of the above statements.

First, That if this inorganic matter be really necessary to the plant, the gradual and constant removal of it from the land ought, by and by, to make the soil poorer in this part of the food of plants.

Second, That the more of the crops which grow upon the land we return to it again in the form of manure, the less will this deterioration be perceptible.

Third, That as many of these inorganic substances—the potash, soda, &c.—are readily soluble in water, the liquid manure of the farmyard, so often allowed to run to waste, must carry with it to the rivers much of the saline matter that ought to be returned to the land.

Fourth, If the rains also are allowed to run over and *wash* the surface of the soil, they will gradually deprive it of those soluble saline substances which appear to be so necessary to the growth of plants. Hence one important benefit of a system of drainage so perfect as to allow the rains to sink into the soil where they fall, and thus

to carry down, instead of away, what they naturally dissolve.

And, *lastly*, That the utility, and often indispensable necessity, of certain artificial manures—though, in some districts, perhaps arising from the natural poverty of the land in some of the mineral substances which plants require — is most frequently owing to a want of acquaintance with the facts above stated, and to the long-continued neglect and waste which has been the natural consequence.

In certain districts, the soil and subsoil contain within themselves an almost unfailing supply of some of these inorganic or mineral substances, so that the waste of them is long in being felt; in others, again, the land contains less, and therefore becomes sooner exhausted. This latter class of soils requires a more careful, and usually a more expensive mode of cultivation than the first; but both will become at length alike unproductive, if that which is yearly taken from the soil is not in some form or other restored to it.

One thing is of essential importance to be remembered by the practical farmer—that the deterioration of land is often an exceedingly slow process. In the hands of successive generations, a field may so imperceptibly become less valuable, that a century even may elapse before the change prove such as to make a sensible diminution in the valued rental. Such slow changes, however, have been seldom recorded; and hence the practical man is occasionally led to despise the clearest theoretical principles, because he has not happened to see them verified in his own limited experience; and to neglect, therefore, the suggestions and the wise precautions which these principles lay before him.

The special agricultural history of known tracts of land

of different qualities, showing how they had been cropped and tilled, and the average produce in grain, hay, and stock every five years, during an entire century, would afford invaluable materials both to theoretical and to practical agriculture.

General illustrations of this sure though slow decay may be met with in the agricultural history of almost every country. In none, perhaps, are they more striking than in the older slave states of North America. Maryland, Virginia, and North Carolina—once rich and fertile—by a long-continued system of forced and exhausting culture, have become unproductive in many places, and vast tracts have been abandoned to apparently hopeless sterility. Such lands it is possible to reclaim, but at what an expense of time, labour, manure, and skilful management! It is to be hoped that the newer states will not thus sacrifice their future power and prospects to present and temporary wealth—that the fine lands of Ohio, Kentucky, and the Prairie states, which now yield Indian corn and wheat, crop after crop, without intermission and without manure, will not be so cropped till their strength and substance is gone, but that a better conducted and more skilful husbandry will continue, *without diminishing the present crops*, to secure a permanent fertility to that naturally rich and productive country.

SECTION V. — PRACTICAL DEDUCTIONS TO BE DRAWN FROM A KNOWLEDGE OF THE INORGANIC CONSTITUENTS OF PLANTS.

Several important practical deductions are to be drawn from what has been stated in regard to the inorganic constituents of plants.

1°. *Why one crop may grow well where another fails.*—Suppose, for example, a crop to require a peculiarly large supply of potash—it may grow well if the soil abound in potash; but if the soil be deficient in potash and abound in lime, then this crop may scarcely grow at all upon it, while another crop to which lime is especially necessary may grow luxuriantly.

2°. *Why mixed crops grow well together.*—If two crops of unlike kinds be sown together, their roots suck in the inorganic substances in different proportions—the one more potash and phosphoric acid perhaps—the other more lime, magnesia, or silica. They thus interfere less with each other than plants of the same kind do—which require the same kinds of food in nearly the same proportions.

Or the two kinds of crop grow with different degrees of rapidity, or at different periods of the year; and thus, while the roots of the one are busy drawing in supplies of inorganic nourishment, those of the other are comparatively idle; and thus the soil is able abundantly to supply the wants of each as its time of need arrives.

3°. *Why the same crop grows better on the same soil after long intervals.*—If each crop demands special substances, or these substances in quantities peculiar to itself, or in some peculiar state of combination, the chances that the soil will be able to supply them are greater, the more distant the intervals at which the same crop is grown upon it. Other crops do not demand the same substances, or in the same proportions; and thus they may gradually accumulate on the soil till it becomes especially favourable to the particular crop we wish to grow.

4°. *Why a rotation of crops is necessary.*—Suppose the soil to contain a certain average supply of all those

inorganic substances which plants require, and that the same corn crop is grown upon it for a long series of years—this crop will carry off some of these substances in larger proportion than others, so that year by year the quantity of those which are thus chiefly carried off will become relatively less. Thus at length the soil, for want of these special substances, will become unable to bear a corn crop at all, though it may still contain a large store of the other inorganic substances which the corn crop does not specially exhaust. Suppose bean or turnip crops raised in like manner for a succession of years, they would exhaust the soil of a different set of substances till it became unable to grow them profitably, though still rich perhaps in those things which the corn crop especially demands.

But grow these crops alternately, then the one crop will draw especially upon one class of substances, the other crop upon another; and thus much larger crops of each will be reaped from the same soil, and for a much longer period of time.

On this principle the benefit of a rotation of crops in an important degree depends.*

5°. *What is meant by exhaustion.*—Thus, exhaustion may either be *general*, arising from the gradual carrying off of all the kinds of food on which plants live—or *special*, arising from the want of one or more of those substances which the crops that have been long grown upon it have specially required.

To repair the former kind of exhaustion, an addition of

* In showing, in the above remarks, how the doctrine of the inorganic part of plants throws light, among other things, upon the use of a rotation of crops, the reader will bear in mind that a knowledge of the organic portion of the plant, and of the living functions of each part in each species, is no less necessary to the full understanding of this intricate subject.

many things to the soil may be necessary;—to repair the latter, it may be sufficient to add a needful supply of one or more things only. In showing how this may be most efficiently and most economically done, chemistry will be of the most essential service to the practical man. Before entering further upon this point, however, it will be necessary to study also the nature of the soil in which plants grow.

CHAPTER V.

Of soils.—Their organic and inorganic portions.—Saline or soluble, and earthy or insoluble, matter in soils.—Examination and classification of soils.—Determination of the per-centage of sand, clay, vegetable matter, and lime.—Diversities of soils and subsoils.

SOILS consist of two parts; of an *organic* part, which can readily be burned away when the soil is heated to redness; and of an *inorganic* part, which is fixed in the fire, and which consists entirely of earthy and saline substances.

SECTION I.—OF THE ORGANIC PART OF SOILS.

The organic part of soils is derived chiefly from the remains of vegetables and animals which have lived and died in or upon the soil, which have been spread over it by rivers and rains; or which have been added by the hands of man, for the purpose of increasing its natural fertility.

This organic part varies very much in quantity in different soils. In some, as in peaty soils, it forms from 50 to 70 per cent of their whole weight; and even in rich long-cultivated soils it has been found, in a few rare cases, to amount to as much as 25 per cent. In general, however, it is present in much smaller proportion, even in our best arable lands. Oats and rye will grow upon a soil containing only 1½ per cent, barley when 2 to 3 per cent are present, while good wheat soils generally contain from 4 to 8 per cent. The rich alluvial soil of the valley of the Nile contains only 5 per cent of dry organic matter. In stiff and very clayey soils, 10 to 12 per

cent is sometimes found. In very old pasture-lands, and in gardens, vegetable matter occasionally accumulates so as to overload the upper soil.

To this organic matter in the soil the name of *humus* has been given by some writers. It contains, or yields to the plant, the ulmic, humic, and other acids already described, (see Chapter II.) It supplies also, by its decay in contact with the air which penetrates the soil, much carbonic acid, which is supposed to enter the roots, and thus to assist the growth of living vegetables. During the same decay, ammonia, as we have already stated, is likewise produced, and this in larger quantity, if animal matter be present in considerable abundance. Other substances, more or less nutritious, are also formed from the organic matter in the soil. These enter by the roots, and contribute to nourish the growing plant, though the extent to which it is fed from this source is dependent, both upon the abundance with which these substances are supplied, and upon the nature of the plant itself, and of the climate in which it grows.

Another influence of this organic portion of the soil, whether naturally formed in it or added to it as manure, is not to be neglected. It contains—as all vegetable substances do—a considerable quantity of inorganic, that is, of saline and earthy matter, which is liberated as the organic part decays. Thus living plants derive from the remains of former races, buried beneath the surface, a portion of that inorganic food which can only be obtained from the soil, and which, if not thus directly supplied, must be sought for by the slow extension of their roots through a greater depth and breadth of the earth in which they grow. The addition of manure to the soil, therefore, places within the easy reach of the roots not only organic but also inorganic food.

SECTION II.—OF THE INORGANIC PART OF SOILS.

The inorganic part of soils—that which remains behind, when everything combustible is burned away by heating it to redness in the open air—consists of two portions, one of which is *soluble* in water, the other *insoluble*. The soluble consists of *saline* substances, the insoluble of *earthy* substances.

1. *The saline or soluble portion.*—In this country, the surface-soil of our fields, in general, contains very little soluble matter. If a quantity of soil be dried in an oven, a pound weight of it taken, and a pint and a-half of pure boiling rain water poured over it, and the whole well stirred and allowed to settle, the clear liquid, when poured off and boiled to dryness, may leave from 30 to 100 grains of saline mixed with a variable quantity of organic matter. This saline matter will consist of common salt, gypsum, sulphate of soda, (Glauber's salts,) sulphate of magnesia, (Epsom salts,) with traces of the chlorides of calcium, magnesium, and potassium, and of potash, soda, lime, and magnesia, in combination with nitric and phosphoric, and with the humic and other organic acids. It is from these soluble substances that the plants derive the greater portion of the saline ingredients contained in the ash they leave when burned.

Nor must the quantity thus obtained from a soil be considered too small to yield the whole supply which a crop requires. *A single grain of saline matter in every pound of a soil a foot deep, is equal to 500 lb. in an acre.* This is more than is carried off from the soil in ten rotations, (forty years,) where only the wheat and barley are sent to market, and the straw and green crops are

regularly, and without loss, returned to the land in the manure.*

In some countries—indeed, in some districts of our own country—the quantity of saline matter in the soil is so great as in hot seasons to form a white incrustation on the surface. It may often be seen in the neighbourhood of Durham; and is more especially to be looked for in districts where the subsoil is sandy and porous, and more or less full of water. In hot weather, the evaporation on the surface causes the water to ascend from the porous subsoil; and as this water always brings with it a quantity of saline matter, which it leaves behind when it rises in vapour, it is evident that, the longer the dry weather and consequent evaporation from the surface continue, the thicker the incrustations will be, or the greater the accumulations of saline matter on the surface. Hence, where such a moist and porous subsoil exists in countries rarely visited by rain, as in the plains of Peru, of Egypt, or of India, the country is whitened over in the dry season with an unbroken snowy covering of the different saline substances above mentioned.

When rain falls, the saline matter is dissolved, and descends again to the subsoil. In dry weather it re-ascends. Hence the *surface-soil* of any field will contain a larger proportion of soluble inorganic matter in the middle of a hot dry season than in one of even ordinary rain. Hence, also, the fine dry weather which, in early summer, hastens the growth of corn, and later in the season favours its ripening, does so probably, among its other modes of action, by bringing up to the roots from beneath a more

* A further portion, it will be recollected, is carried off in the cattle that are sent to market, or is lost in the liquid manure that is wasted, or is washed out by the rains from the soil or from the manure ; all these are here neglected.

ready supply of those saline compounds which the crop requires for its healthful growth. In some countries, however, this saline matter ascends in such quantity as to render the soil unfit to grow the more tender crops. Thus, on the plains of Attica, when the rainy season ends, saline substances begin to rise to the surface in such abundance as by degrees entirely to burn up or prevent the growth of grass, though abundant wheat crops are yearly ripened.

2. *The earthy or insoluble portion.*—The earthy or insoluble portion of soils rarely constitutes less than 95 lb. in a hundred of their whole weight. It consists chiefly of *silica* in the form of *sand*—of *alumina* mixed or combined with silica in the form of *clay*—and of *lime* in the form of *carbonate of lime.* It is rarely free, however, from two or three per cent of oxide of iron; and where the soil is of a red colour, this oxide is often present in still larger proportion. A trace of magnesia also may be almost always detected, and a minute quantity of phosphate of lime. The principal ingredients, however, of the earthy part of all soils are sand, clay, and lime; and soils are named or classified according to the quantity of each of these three they may happen to contain.

a. If an ounce of soil be intimately mixed with a pint of water till it is perfectly softened and diffused through it, and if, after shaking, the heavy parts be allowed to settle for a few minutes, the sand will subside, while the clay—which is in finer particles, and is less heavy—will still remain floating. If the water and fine floating clay be now poured into another vessel, and be allowed to stand till the water has become clear, the sandy part of the soil will be found on the bottom of the first vessel, and the clayey part on that of the second, and they may be dried and weighed separately.

b. If 100 grains of dry soil, not peaty or unusually rich

in vegetable matter, leave no more than 10 of clay when treated in this manner, it is called a *sandy soil;* if from 10 to 40, a *sandy loam;* if from 40 to 70, a *loamy soil;* if from 70 to 85, a *clay loam;* from 85 to 95, a *strong clay soil;* and when no sand is separated at all by this process, it is a pure *agricultural clay.*

c. The *strong clay soils* are such as are used for making tiles and bricks; the pure *agricultural clay* is such as is commonly employed for the manufacture of pipes, (pipe-clay.) This pure clay is a chemical *compound* of silica and alumina, in the proportion of about 60 of the former to 40 of the latter. Soils of pure clay rarely occur—it being well known to all practical men that the strong clays, (tile clays,) which contain from 5 to 15 per cent of sand, are brought into arable cultivation with the greatest possible difficulty. It will rarely, almost never, happen, therefore, that arable land will contain more than 30 to 35 per cent of alumina.

d. If a soil contain more than 5 per cent of carbonate of lime, it is called a *marl;* if more than 20 per cent, it is a *calcareous* soil. *Peaty soils,* of course, are those in which the vegetable matter predominates very much.

e. The quantity of vegetable or other organic matter is determined by drying the soil *well* upon paper in an oven, until it ceases to lose weight—taking care that the heat is not so great as to char the paper—and then burning in the open air a weighed quantity of the dried soil: the loss by burning is *nearly all* organic matter. In stiff clays this loss will include also a portion of water, which is not wholly driven off from such soils by drying upon paper in the way described.

f. To estimate the lime, a quantity of the soil should be heated in the air till the organic matter is burned away. A weighed portion, (200 or 300 grains,) should then

be diffused through half a pint of cold water mixed with half a wine-glassful of spirit of salt, (muriatic acid,) and allowed to stand for a few hours, with occasional stirring. When minute bubbles of gas cease to rise from the soil, the water is poured off, the soil dried, heated to redness as before, and weighed : the loss is nearly all lime.*

SECTION III.—OF THE DIVERSITIES OF SOILS AND SUBSOILS.

1st. *Soils.*—Though the substances of which soils *chiefly* consist are so few in number, yet every practical man knows how very diversified they are in character—how very different in agricultural value. Thus, in some of our southern counties, we have a white soil, consisting apparently of nothing else but chalk; in the centre of England a wide plain of dark-red land; in the border counties of Wales, and on many of our coal-fields, tracts of country almost perfectly black; while yellow, white, and brown sands and clays give the prevailing character to the soils of other districts. Such differences as these arise from the different proportions in which the sand, lime, clay, and the oxide of iron and organic matter which colour the soils, have been mixed together.

But how have they been so mixed—differently in different parts of the country? By what natural agency? For what end?

2d. *Subsoil.*—Again, the surface-soil rests on what is usually denominated the *subsoil.* This also is very variable in its character and quality. Sometimes it is a porous sand or gravel, through which water readily ascends from beneath, or sinks in from above; sometimes

* Unless the soil happen to contain a large quantity of magnesia, or of oxide of iron in combination with carbonic or with some organic acids, which is not often the case.

it is light and loamy, like the soil that rests upon it; sometimes stiff, and more or less impervious to water.

The most ignorant farmer knows how much the value of a piece of land depends upon the character of the surface-soil,—the intelligent improver understands best the importance of a favourable subsoil. "When I came to look at this farm," said an excellent agriculturist to me, "it was spring, and damp, growing weather: the grass was beautifully green, the clover shooting up strong and healthy, and the whole farm had the appearance of being very good land. Had I come in June, when the heat had drunk up nearly all the moisture which the *sandy subsoil* had left in the surface, I should not have offered so much rent for it by ten shillings an acre." He might have said also, "Had I taken a spade, and dug down 18 inches in various parts of the farm, I should have known what to expect in seasons of drought."

But how come subsoils thus to differ—one from the other—and from the surface-soil that rests upon them? Are there any principles by which such differences can be accounted for—by which they can be foreseen—by the aid of which we can tell what kind of soil may be expected in this or that district, even without visiting the spot, and on what kind of subsoil it is likely to rest?

Geology explains the cause of many of these differences, and supplies us with principles by which we can predict the general quality of both soils and subsoils in the several parts of entire kingdoms; and where the soil is of inferior quality, and yet susceptible of improvement, the same principles indicate whether the means of improving it are likely to exist in any given locality, or to be attainable at a reasonable cost.

It will be proper shortly to illustrate these direct relations of geology to agriculture.

CHAPTER VI.

Direct relations of geology to agriculture.—Origin of soils.—Causes of their diversity.—Relation of soils to the rocks on which they rest.—Constancy in the relative position and character of the stratified rocks.—Relation of this fact to practical agriculture.—Of primary, secondary, tertiary, and post-tertiary rocks.—Different soils observed upon each of these divisions along the Atlantic sea-board of North America.

GEOLOGY is that branch of knowledge which embodies all ascertained facts in regard to the nature and internal structure, both physical and chemical, of the solid parts of our globe. This science has many close relations with practical agriculture. It especially throws much light on the nature and origin of soils—on the causes of their diversity—on the agricultural capabilities, absolute and comparative, of different farming districts and countries—on the unlike effects produced by the same manure on different soils—on the kind of materials, by admixture with which they may be permanently improved—and on the sources from which these materials may be derived.

It tells beforehand, also, and by a mere inspection of the map, what is the general character of the land in this or that district of a country—where good land is to be expected—where improvements are likely to be effected—of what kind of improvements this or that district will be susceptible—and where the intending purchaser may hope to lay out his money to the greatest advantage.

SECTION I.—OF THE CRUMBLING OF ROCKS AND THE ORIGIN OF SOILS.

If we dig down through the soil and subsoil to a sufficient depth, we always come sooner or later to the solid rock. In many places the rock actually reaches the surface, or rises in cliffs, hills, or ridges, far above it. The surface (or crust) of our globe, therefore, consists everywhere of a more or less solid mass of rock, overlaid by a covering, generally thin, of loose materials. The upper or outer part of these loose materials forms the soil.

The geologist has travelled over great part of the earth's surface, has examined the nature of the rocks which everywhere repose beneath the soil, and has found them to be very unlike in appearance, in hardness, and in composition—in different countries and districts. In some places he has met with a sandstone, in other places a limestone, in others a slate or hardened rock of clay. But a careful comparison of all the kinds of rock he has observed has led him to the general conclusion *that they are all either sandstones, limestones, or clays of different degrees of hardness, or a mixture in different proportions of two or more of these kinds of matter.*

When the loose covering of earth is removed from the surface of any of these rocks, and this surface is left exposed, summer and winter, to the action of the winds and rains and frosts, it may be seen gradually to crumble away. Such is the case even with many of those which, on account of their greater hardness, are employed as building-stones, and which, in the walls of houses, are kept generally dry; how much more with such as are less hard, or lie beneath a covering of moist earth, and are continually exposed to the action of water. The natural

crumbling of a naked rock thus gradually covers it with loose materials, in which seeds fix themselves and vegetate, and which eventually form a soil. The soil thus produced partakes necessarily of the chemical character and composition of the rock on which it rests, and to the crumbling of which it owes its origin. If the rock be a sandstone, the soil is sandy—if a claystone, it is a more or less stiff clay—if a limestone, it is more or less calcareous—and if the rock consist of any peculiar mixture of those three substances, a similar mixture is observed in the earthy matter into which it has crumbled.

Led by this observation, the geologist, after comparing the rocks of different countries with one another, compared next the soils of various districts with the rocks on which they immediately rest. The *general* result of this comparison has been, that in almost every country the soils, as a whole, have a resemblance to the rocks beneath them, similar to that which the loose earth derived from the crumbling of a rock before our eyes bears to the rock of which it lately formed a part. The conclusion, therefore, is irresistible, that soils, generally speaking, have been formed by the crumbling or decay of the solid rocks—that there was a time when these rocks were naked and without any covering of loose materials—and that the accumulation of soil has been the slow result of the natural degradation or wearing away of the solid crust of the globe.

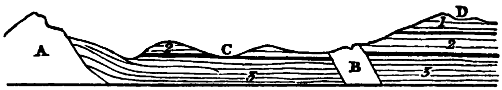
SECTION II.—CAUSE OF THE DIVERSITY OF THE SOILS.

The cause of the diversity of soils in different districts, therefore, is no longer obscure. If the subjacent rocks in two localities differ, the soils met with there are likely to differ also, and in an equal degree.

But why, it may be asked, do we find the soil in some countries uniform in mineral * character and general fertility over hundreds or thousands of square miles, while in others it varies from field to field—the same farm often presenting many well-marked differences both in mineral character and in agricultural value? A chief cause of this is to be found in the mode in which the different rocks are observed to lie—upon or by the side of each other.†

1. Geologists distinguish rocks into two classes, the *stratified* and the *unstratified*. The former are found lying over each other in separate beds or *strata*, like the leaves of a book when laid on its side, or like the layers of stones in the wall of a building. The latter—the unstratified rocks—form hills, mountains, or sometimes ridges of mountains, consisting of one more or less solid mass of the same material, in which no layers or strata are usually anywhere or distinctly perceptible. Thus, in the following diagram, (No. 1,) A and B represent *unstratified* masses, in connection with a series of *stratified* deposits, 1 2 3, lying over each other in a horizontal position. On A one kind of soil will be formed, on C another, on B a third, and on D a fourth—the rocks being all different from each other.

No. 1.



If from A to D be a wide valley of many miles in extent, the undulating plain at the bottom of the valley, resting in great part on the same rock, (2,) will be covered

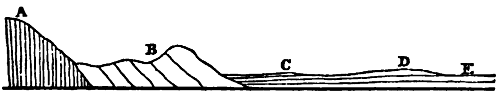
* That is, containing the same general proportions of sand, clay, lime, &c., or coloured red by similar quantities of oxide of iron.

† For another important cause, see Section II. of Chapter VIII.

by a similar soil. On B the soil will be different for a short space; and again it will differ at the bottom of the valley C, and on the first ascent to A, at both of which places the rock (3) rises to the surface. In this case the stratified rocks lie horizontally; and it is the undulating nature of the country which, bringing different kinds of rock to the surface, causes a necessary diversity of soil.

2. But the degree of *inclination* which the beds possess is a more frequent cause of variation in the characters of the soil in the same district, and even at very short distances. This is shown in the annexed diagram, (No. 2,) where A B C D E represent the mode in which the stratified rocks of a district of country not unfrequently occur in connection with each other.

No. 2.



Proceeding from E in the plain, the soil would change when we came upon the rock D, but would continue pretty uniform in quality till we reached the layer C. Each of these layers may stretch over a comparatively level tract of perhaps hundreds of miles in extent. Again, on climbing the hill-side, another soil would present itself, which would not change till we arrived at B. Then, however, we begin to walk over the edges of a series of beds, and the soil may vary with every new *stratum* or bed we pass over, till we gain the ascent to A, where the beds are much thinner, and where, therefore, still more frequent variations may present themselves.

Everywhere over the British islands valleys are hollowed out, as in the former of these diagrams, (No. 1,) by which the different rocks beneath are in different places

exposed and differences of soil produced; or the beds are more or less inclined, as in the latter diagram, (No. 2,) causing still more frequent variations of the land to appear. By a reference to these facts, therefore, many of the *greater* diversities which the soils of the country present may be satisfactorily accounted for.

SECTION III.—OF THE CONSTANCY IN MINERAL CHARACTER, AND ORDER OF SUCCESSION, WHICH EXISTS AMONG THE STRATIFIED ROCKS.

Another fact, alike important to agriculture and to geology, is the natural order or mode of arrangement in which the stratified rocks are observed to occur in the crust of the globe. Thus, if 1 2 3 in diagram No. 1 represent three different kinds of rock—a limestone, for example, a sandstone, and a hard clay rock (a shale or slate) lying over each other in the order here represented—then, in whatever part of the country, nay, in whatever part of the world these same rocks are met with, they will always be found in the same position. *The bed* 2 *or* 3 *will never be observed to lie over the bed* 1.

This fact is important to geology, because it enables this science to arrange all the stratified rocks in a certain invariable order—which order indicates their relative age or antiquity—since that rock which is lowest, like the lowest layer of stones in the wall of a building, must generally have been the first deposited, or must be the oldest. It also enables the geologist, on observing the kind of rock which forms the surface in any country, to predict at once whether certain other rocks are likely to be met with in that country or not. Thus at C, (diagram No. 1,) where the rock 3 comes to the surface, he knows it would be in vain, either by sinking or otherwise, to

seek for the rock 1, the natural place of which is far above it; while, at D, he knows that by sinking he is likely to find either 2 or 3, if it be worth his while to seek for them.

To the agriculturist this fact is important, among other reasons,—

1. Because it enables him to predict whether certain kinds of rock, which may be used with advantage in improving his soil, are likely to be met with within a reasonable distance or at an accessible depth. Thus, if the bed D (diagram No. 2) be a limestone, the instructed farmer at E knows that it is not to be found by sinking into his own land, and therefore brings it from D; while to the farmer upon C it may be less expensive to dig down to the bed D in one of his own fields, than to cart it from a distant spot, where it occurs on the surface. Or, if the farmer requires clay, or marl, or sand, to ameliorate his soil, this knowledge of the constant relative position of beds enables him to say where these materials are to be got, or where they are to be looked for, and whether the advantage to be derived is likely to repay the cost of procuring them.

2. It is observed that, when the soil on the surface of each of a series of rocks, such as C or D or E, (diagram No. 2,) is uniformly bad, *it is almost uniformly of better quality at the point where the two rocks meet.* Thus C may be dry, sandy, and barren; D may be a cold unproductive clay; and E a more or less unfruitful limestone soil; yet at either extremity of the tract D, where the soil is made up of an admixture of the decayed portions of the two adjacent rocks, the land may be of average fertility—the sand of C may adapt the adjacent clay to the growth of turnips, while the lime of E may cause it to yield large returns of wheat.* Thus, to the tenant in looking out

* See p. 93.

for a farm, or to the capitalist in seeking an eligible investment, a knowledge of the mutual relations of geology and agriculture will often prove of the greatest assistance. But how little is such really useful knowledge diffused among either class of men—how little have either tenants or proprietors been hitherto guided by it in their choice of the localities in which they desire to live!

3. The further fact that the several stratified rocks are remarkably constant in their general mineral character, renders this knowledge of the order of relative superposition still more valuable to the agriculturist. Thousands of different beds are known to geologists to occur on various parts of the earth's surface—each occupying its own unvarying place in the series. Most of these beds also, when they crumble or are worn down, produce soils possessed of some peculiarity by which their general agricultural capabilities are more or less affected,—and these peculiarities may *generally* be observed in soils formed from rocks of the same age—that is, occupying the same place in the series—in whatever part of the world we find them. Hence, if the agricultural geologist be informed that his friend has bought, or is in treaty for a farm or an estate, and that it is situated upon such and such a rock, or geological formation, or is in the immediate neighbourhood of such another,—he can immediately give a very probable opinion in regard to the agricultural value of the soil, whether the property be in England, in Australia, or in New Zealand. If he knows the nature of the climate also, he will be able to estimate with tolerable correctness how far the soil is likely to repay the labours of the practical farmer—nay, even whether it is likely to suit better for arable land or for pasture; and if for arable, what species of grain and root crops it may be expected to produce most abundantly.

These facts are so very curious, and illustrate so beautifully the value of geological knowledge—if not to A and B, the holders and proprietors of this and that small farm, yet to enlightened agriculturists, to scientific agriculture in general—that I shall explain this part of the subject more fully in a separate section. To those who are now embarking in such numbers in quest of new homes in our numerous colonies—who hope to find, if not a more willing, at least a more attainable soil in new countries—no kind of agricultural knowledge can at the outset,—I may say, even through life—be so valuable as that to which the rudiments of geology will lead them. Those who prepare themselves the best for becoming farmers or proprietors in Canada, in New Zealand, or in wide Australia, leave their native land in general without a particle of that preliminary practical knowledge which would qualify them to say, when they reach the land of their adoption, "on this spot rather than on that—in this district, rather than that,—will I purchase my allotment, because, though both appear equally inviting, yet I know, from the geological structure of the country, that here I shall have the more permanently productive soil; here I am more within reach of the means of agricultural improvement; here, in addition to the riches of the surface, my descendants may hope to derive the means of wealth from mineral riches beneath." And this oversight has arisen chiefly from the value of such knowledge not being understood—often from the very nature of it being unknown, even to otherwise well-instructed practical men. It is not to men well skilled merely in the details of local farming, and who are therefore deservedly considered as authorities, and good teachers in regard to local or district practice, that we are to look for an exposition, often not even for a correct appreciation of those general principles

on which a universal system of agriculture must be based—without which, indeed, it must ever remain a mere collection of empirical rules, to be studied and laboriously mastered in every new district we go to—as the traveller in foreign lands must acquire a new language every successive frontier he passes. England, the mistress of so many wide and unpeopled lands, over which the dwellings of her adventurous sons are hereafter to be scattered, on which their toil is to be expended, and the glory of their motherland by their exertions to be perpetuated—England should especially encourage all such learning, and the sons of English farmers should willingly avail themselves of every opportunity of acquiring it.

SECTION IV.—OF THE SUBDIVISIONS OF THE STRATIFIED ROCKS, AND OF OBSERVED DIFFERENCES AMONG THE SOILS THAT REST UPON THEM.

The thousands of beds or strata of which I have spoken as lying one over the other in the crust of the globe, have—partly for convenience, and partly in consequence of certain remarkably distinctive characters observed among them—been separated by geologists into three great divisions. The *primary* are the lowest and the oldest; the *secondary* lie over these; and the *tertiary* are the uppermost, and have been most recently formed. The sands, gravels, clays, and alluvial deposits, which in many places overlie the solid rocks and the beds of soft limestone, in many places formed by calcareous springs, are often spoken of as *post-tertiary*.

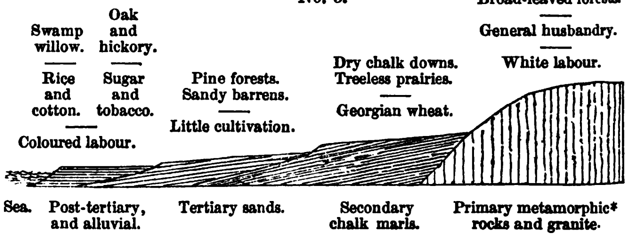
In some countries, on the surface of which these several divisions of the strata are seen to succeed each other very closely, the character of the surface soil and its agricultural capability are also seen to vary as we pass from the

rocks of the one epoch to those of the other. This is the case, for example, in the more southernly of the United States of America which lie along the Atlantic border. As we walk inland from the sea-shore, we pass over low and swampy, but rich muddy flats, which yield large returns of sea-island cotton and rice. As we proceed, the ground gradually rises above the sea-level—becomes firmer and drier—and instead of the swamp willow and cypress, bears the hickory and the oak. Tobacco and sugar are the marketable crops on this drier land, and Indian corn the staple food of the coloured population. After twenty miles or so, the edge of this drier alluvial plain is reached, and we ascend a low escarpment or terrace of yellow sand. Here we find ourselves amid thin forests of unmixed natural pine, growing upon a poor sandy soil; and till we cross this belt and reach a second terrace, few corn-fields, or attempts at clearing for the purposes of cultivation, meet the eye. The new terrace presents the remarkable contrast of an open prairie, void of trees, covered with a thin soil waving with grass, and resting, like our English downs, on chalk rocks beneath. This tract is dry and deficient in water; but the thin soil, when turned over, yields crops of corn, and bears, among others, a variety of hard wheat, known in the market by the name of Georgian wheat. Still farther on this prairie is passed, and we ascend hilly slopes, upon which clays and loams of various qualities and capabilities occur at intervals intermingled, and broad-leaved trees of various kinds ornament the landscape. It is a country fitted for general husbandry, propitious to skill and industry, and, by its climate, adapted to the constitution of settlers of European blood.

These changes in agricultural character and capability are coincident with changes in the geological age of the

beds which form its surface. This I have shown in the following section of the coast-line in question, from the sea to the mountains. The letterpress below the section indicates the geological formations; that placed above it indicates, first, the natural vegetation, and then the kind of husbandry and of labour which are best adapted to each.

No. 3.



In this section the reader will observe a close general relation between the changes in geological and agricultural character which appear on the several successive terraces or flats of land which intervene between the shores of the Atlantic and the slopes of the Alleghany Mountains. Where the most recent or alluvial loams and rich clays end, there the tobacco, Indian corn, and even wheat culture, for the time, end also. The tertiary sands belong to a more ancient epoch, and to them are limited, by a strictly defined boundary on each side, the dark pine forests which are so striking a feature of the country. On the still older chalk, again, the treeless prairie and flinty wheat country is as distinctly limited by the formations on either hand; and beyond this, again, the changed forests and cultivation of the higher country are determined by the change in nature and in age which the rocks of this region exhibit.

* The word metamorphic here used means changed or altered—as clay, for example, is changed when it is baked into tiles or bricks.

CHAPTER VII.

Subdivisions of the tertiary, secondary, and primary groups of rocks.—Agricultural relations of the crag and London clay.—Fossil phosphates of the crag ; quantity and value of these.—Soils of the London and plastic clays.—Of the chalk and green-sand.—Ware malt.—Clays of the Weald and Lias.—Rich soils of the new red sandstone.—Contrast between those of the millstone grit and mountain limestone.—Soils of the Silurian, Cambrian, and Mica slate rocks.—General conclusions as to the relations of geology to agriculture.

BUT the several great groups of strata of which we have spoken under the names of primary, secondary, &c., are themselves broken up or subdivided by geologists into a variety of subdivisions called systems and formations, each of which possesses its peculiar mineral characters and special agricultural relations. These, in so far as relates to the geology of our own country, it will be proper briefly to indicate.

SECTION I.—THE TERTIARY STRATA.

The tertiary strata, as they occur in England, consist chiefly of the crag, which lies above, and the London and plastic clays, which follow each other underneath.

1. The *Crag* consists of a mass of rolled pebbles mixed with marine shells and corals, and resting upon beds of sand and marl. It is in places as much as 50 feet in thickness, though generally of less depth, and forms a strip of flat land, a few miles in width, along the eastern shores of

Norfolk and Suffolk. The soil is generally fertile, but varies in value from 5s. to 25s. an acre of rent.

This crag is chiefly interesting to the agriculturist from its containing hard, rounded, flinty nodules—often spoken of as *coprolites*—in which as much as 50 per cent of phosphate of lime (bone-earth) is frequently found. These nodules are scattered through the body of the marls, and through the subsoils of the fields far inland, and are collected for sale to the manufacturers of super-phosphate of lime and other artificial manures. Some parties are said to have dug up as much as 60 or 70 tons a-week.*

2. *The London and plastic clays*, from 500 to 900 feet thick, consist of stiff, almost impervious, dark-coloured clays—the soils formed from which are still chiefly in pasture. The lower beds—the plastic clay—are mixed with sand, and produce an arable soil; but extensive heaths and wastes rest upon them in Berkshire, Hampshire, and Dorset. The crops of corn and roots yielded by the stiff clay soils of these strata have hitherto, in many districts, been found insufficient to pay the cost of raising them. The drain and the subsoil plough, with lime or chalk—in which these clays are very deficient, and for the addition of which they are very grateful—would render them more productive and more profitable to the farmer.

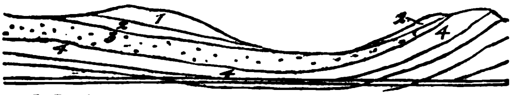
* The cost of digging up, screening, cleaning, &c., of these nodules, is about 5s. a ton, and they are delivered on board the vessel at 30s. to 45s. The quantity of the fossils which is scattered over this part of the county, and the treasure they are now proving to the owners of the land, may be judged of from two facts stated by Mr Herapath, (*Jour. Royal Agric. Soc.*, xii. p. 93,) "that £60, £70, and £80, have been repeatedly given for leave to dig over a two-acre field;" and "that the land itself is actually improved by the course of treatment to which it is subjected when excavating for the fossils."

SECTION II.—THE SECONDARY STRATA.

3. The *Chalk*, about 600 feet in thickness, lies below the London and plastic clays above described. It consists—as shown in the section No. 4—in the upper part,

No. 4.

Suffolk. Mouth of the Thames. Kent.



1. London clay.
2. Plastic clay.
3. Upper chalk, with flints.
4. Under chalk, without flints.

of a purer chalk with layers of flint, (3); in the lower, of a marly chalk without flints, (4.) The soil of the upper chalk is chiefly in sheep-walks; that of the lower chalk is very productive of corn. In some localities, (Croydon,) the arable soils of the upper chalk have lately been rendered much more productive in corn and beans by deep ploughing, and thus mixing with the upper soil as much as 6 or 8 inches of the inferior chalk. Excellent crops of carrots also have been obtained by deep-forking such land.

The general and comparative agricultural value of the soils upon the chalk may, to a certain extent, be judged of by the fact, that, in the lowest-rented counties in England, chalk is the prevailing rock.

4. The *Green-sand*, 500 feet thick, consists of 150 feet of clay, with about 100 feet of a greenish, more or less indurated, sand above, and 250 feet of sand or sandstone below it. The upper sand forms a very productive arable soil; but the clay forms impervious wet and cold lands, chiefly in pasture. The lower sand is generally unproductive.

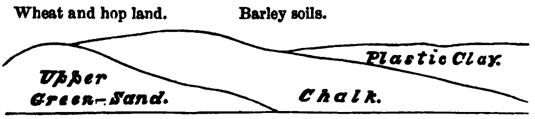
In the green-sand, both upper and lower, but especially

in the upper, beds of marl occur, in which are found layers of so-called coprolites and other organic remains, rich in phosphate of lime. To the presence of these beds is ascribed the fertility of the soil of the upper green-sand, which in some localities is very remarkable, and, as at Farnham in Surrey, is found to be especially favourable to the growth of hops. The organic remains are in some places so abundant, that, as in the crag, they are sought for and dug up, as a natural source of the phosphate of lime, usually supplied to the soil directly in the form of bones.

It is an important agricultural remark, that where the plastic clay comes in contact with the top of the chalk, an improved soil is produced; and that where the chalk and the green-sand mix, extremely fertile patches of country present themselves.

The following imaginary section shows the relative positions of these two fertile strips of country, above and below the chalk. At the contact with the plastic clay it is particularly adapted for the growth of barley, which, for quality and malting properties, is not excelled by any in the kingdom. In Essex, barley grown on this soil is principally sold to maltsters at Stortford, &c.; and when malted, is sold again in London under the name of Ware malt. This name is derived from Ware in Hertfordshire, a market town standing on a similar soil.

No. 5.



The soils at the contact of the chalk and upper green-sand are celebrated for their crops of wheat, in producing

which the phosphates in the marls of the upper green-sand are supposed to have some influence.

5. The *Wealden formation*, which succeeds the green-sand, is nearly 1000 feet thick, and consists of 400 feet of sand, covered by 300 of clay, resting upon 250 of marls and limestones. The clay forms the poor, wet, but improvable pastures of Sussex and Kent. These clays, in many places, harden like a brick when dried in the air; and clods which have lain long in the sun, ring, when struck, like a piece of pottery. By draining alone, their produce has been raised from 16 to 40 bushels of wheat an acre. On the sands below the clay rest heaths and brushwood; but where the marls and limestones come to the surface, the land is of better quality, and is susceptible of profitable arable culture.

6. In the *Upper oolite*, of 600 feet in thickness, we have a bed of clay (Kimmeridge clay) 500 feet thick, covered by 100 feet of sandy limestones. The clay lands of this formation are difficult and expensive to work, and are therefore chiefly in old pasture. The sandy limestone soils above the clay are also poor; but where they rest immediately upon, and are intermixed with, the clay, excellent arable land is produced.

7. The *Middle oolite*, of 500 feet, consists also of a clay, (Oxford clay,) dark blue, adhesive, often rich in lime, and nearly 400 feet thick, covered by 100 feet of limestones and sandstones. These latter produce good arable land where the lime happens to abound, but the clays, especially while undrained, form close heavy compact soils, most difficult and expensive to work. In wet weather they are often adhesive like bird-lime, and in dry summers become hard like stone, so as to require a pick-axe to break them. They have therefore hitherto been very partially brought into arable culture. The extensive

pasture-lands of Bedford, Huntingdon, Northampton, Lincoln, Wilts, Oxford, and Gloucester, rest chiefly upon this clay; as do also the fenny tracts of Lincoln and Cambridge. The use of burned clay upon the arable land has, in some parts of this clay district, been of much advantage.

8. The *Lower* or *Bath oolite*, of 500 feet in thickness, consists of many beds of limestone and sandstone, with about 200 feet of clay in the centre of the formation. The soils are very various in quality, according as the sandstone or limestone predominates in each locality. The clays are chiefly in pasture: the rest is more or less productive, easily worked, arable land. In Gloucester, Northampton, Oxford, the east of Leicester, and in Yorkshire, this formation is found to lie immediately beneath the surface, and a little patch of it occurs also on the south-eastern coast of Sutherland.

9. The *Lias* is an immense deposit of blue clay, from 500 to 1000 feet in thickness, which produces cold, blue, unproductive clay soils. It forms a long stripe of land, of varying breadth, which extends, in a south-western direction, from the mouth of the Tees, in Yorkshire, to Lyme Regis, in Dorset. It is chiefly in old, and often very valuable pasture. An efficient system of drainage will by-and-by convert much of this clay into most productive wheat land.

10. The *New red sandstone*, though only 500 feet in thickness, forms the surface of nearly the whole central plain of England, and stretches northwards through Cheshire to Carlisle and Dumfries. It consists of red sandstones and red marls, the soils produced from which are easily and cheaply worked, and form some of the richest and most productive arable lands in the island. This is in some degree indicated by the fact that the three

highest-rented counties in England rest chiefly upon this rock. In whatever part of the world the red soils of this formation have been met with, they have been found to possess in general the same valuable agricultural capabilities.

11. The *Magnesian limestone*, from 100 to 500 feet in thickness, is covered by a stripe of generally poor thin soil, extending from Durham to Nottingham, capable of improvement as arable land by high farming, but bearing naturally a poor pasture, intermingled with sometimes magnificent furze.

12. The *Coal measures*, from 300 to 3000 feet thick, consist of beds of grey sandstone, and of dark blue shale, or hardened clay, intermingled *(inter-stratified)* with beds of coal. Where the sandstones come to the surface, the soil is thin, poor, hungry, sometimes almost worthless. The shales, on the other hand, produce stiff, wet, almost unmanageable clays—not unworkable, yet expensive to work, and requiring draining, lime, skill, capital, and a zeal for improvement to be applied to them, before they can be made to yield the remunerating crops of corn they are capable of producing. The blaes or shales of this formation, when dug out of cliffs or brought from coal-mines, may be laid with advantage on loose sandy soils, and even, it is said, on the stiff whitish clays almost destitute of vegetable matter, which, as in Lanarkshire, occasionally occur on the surface of our coal-fields.

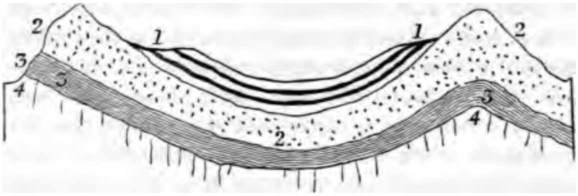
13. To the *Millstone grit*, of 600 feet or upwards in thickness, the same remarks apply. It lies below the coal, but is often only a repetition of the sandstones and shales of the coal measures, and forms in many cases soils still more worthless. Where the sandstones prevail, large tracts lie naked, or bear a thin and stunted heath. Where the shales abound, the naturally difficult soils of the coal-shales again recur. The rocks of this formation generally

approach the surface, around the outskirts of our coal-fields.

This arises from the circumstance that our coal measures often lie in basin-shaped deposits, from beneath each edge of which, the millstone grit and mountain limestone rocks rise up to the surface. This is illustrated by the annexed section, (No. 6,) across a part of Lancashire, in which 1 represents the coal measures; 2 the coarse sandstones, &c. of the millstone grit; 3 a thick shale-bed, which often overlies the thick masses of mountain limestone represented by 4.

No. 6.

Pendle hill. 1803. Boulsworth hill. 1689.



The traveller passes off the poor, often cold and wet, clay soils of the coal measures, on to the equally poor lands of the millstone grit, and over its top, as at Pendle hill, descends upon the sweet herbage and rich dairy pastures of the mountain limestone at 4.

The section shows also how in this country the millstone grit often rises into high hills. These are then covered with poor heaths and worthless moors, while limestone hills of equal height bear green herbage to the very top.

14. The *Mountain limestone*, 800 to 1000 feet thick, is a hard blue limestone rock, separated here and there into distinct beds by layers of sandstones, of sandy slates, or of bluish-black shales like those of the coal measures. The soil upon the limestone is generally thin, but produces

a naturally sweet herbage, everywhere superior in value to that which grows on the sandier soils of the millstone grit. When the limestone and clay (shale) adjoin each other, as where 3 and 4 in the section meet, arable land occurs, which is naturally productive of oats, and, where the climate is favourable, may, by skilful treatment, be converted into good wheat land. In the north of England—in Derbyshire, for example, and among the Yorkshire dales—a considerable tract of country is covered by these rocks; but in Ireland they form nearly the whole of the interior of the island.

15. The *Old red sandstone* varies in thickness from 500 to 10,000 feet. It possesses many of the valuable agricultural qualities of the *new red*, (No. 10,) consisting, like it, of red sandstones and red marls, which crumble down into rich red soils. Such are the soils of Brecknock, Hereford, and part of Monmouth; of part of Berwick and Roxburgh; of Haddington and Lanark; of southern Perth; of either shore of the Moray Firth; and of part of Sutherland, Caithness, and the Orkney islands. In Ireland, also, these rocks abound in Tyrone, Fermanagh, and Monaghan; in Waterford, in Mayo, and in Tipperary. In all these places the soils they form are generally the best in their several neighbourhoods. Here and there, however, where the sandstones are harder, more silicious and impervious to water, tracts, sometimes extensive, of heath and bog occur; while in others the rocks have crumbled into hungry sands, which swallow up the manure, and are expensive to maintain in arable culture.

SECTION III.—THE PRIMARY STRATA.

The primary stratified rocks, which lie underneath all those already described, are separable into three natural

divisions; the *Silurian** above, which contain the remains of animals in a fossil state; the *Cambrian*† below, in which no animal remains have yet been discovered; and, lowest of all, the *mica slate* and *gneiss* rocks, which exhibit marks of change or alteration by the agency of heat. Hence these last are often spoken of as *metamorphic*, or changed rocks.

16. The *Upper Silurian system* is nearly 4000 feet in thickness, and forms the soils which cover the lower border counties of Wales. It consists of sandstones and shales, with occasional limestones; but the soils formed from these beds take their character from the general abundance of the clay. They are cold—usually unmanageable *muddy* clays; with the remarkably inferior agricultural value of which the traveller is immediately struck, as he passes westward from the red sandstones of Hereford to the Upper Silurian rocks of the county of Radnor.

17. The *Lower Silurian* rocks are many thousand feet in thickness, and in Wales lie to the west and north of the Upper Silurian rocks. They consist, on the upper part, of about 25,000 feet of sandstone, on which, when the surface is not naked, barren heaths alone rest.

Beneath these sandstones lie 1200 feet of sandy and earthy limestones, from the decay of which, as may be seen on the southern edge of Caermarthen, fertile arable lands are produced.

The high land, which stretches across the whole of southern Scotland, from St Abb's Head to Portpatrick, including the Lammermuir hills, so far as they have yet been examined, consists of strata belonging to the upper part of the Lower Silurian, and the lower part of the

* Or older *Palaiozoic*, as containing evidences of most ancient life.

† Or *Azoic*, from containing no traces of life.

Upper Silurian. The soils in general are of inferior quality, the slaty rocks crumbling with difficulty, and being poor in lime. Cold and infertile farms cover the higher grounds, and wide heathy moors and bogs.

18. The *Cambrian* system—meaning by this term unaltered rocks, containing no fossils—is at present a subject of dispute among geologists, and its limits even in our own island are not well defined. It is probably many thousand feet in thickness—lies beneath the Lower Silurian—and in its agricultural relations has much resemblance to these rocks. It consists in great part of slaty rocks, more or less hard, which often crumble very slowly, and almost always produce either poor and thin soils—or cold, difficultly manageable clays, expensive to work, and requiring *high farming* to bring them into profitable arable cultivation. In Cornwall, western Wales, the mountains of Cumberland; in the mountains of Tipperary, in the extreme south of Ireland, on its east coast, and far inland from the bay of Dundalk, such slaty rocks occur, though the limits of the two formations have not been everywhere defined. Patches of rich, well-cultivated land occur here and there in these districts, with much also that is improvable; but the greater part is usurped by worthless heaths and extensive bogs. On the difficult soils of those formations—thinly peopled, inhabited by small farmers with little capital, and therefore hitherto neglected—much improvement is now here and there appearing; and the introduction of the drain promises to make much corn grow, where little food, either for man or beast, was previously produced. These rocks in general contain little lime, and therefore, after the drain, the addition of lime is usually one of the most certain means of increasing the productiveness of the soils formed from them.

19. The *Mica slate* and *Gneiss systems* are of unknown thickness, and consist chiefly of hard and slaty rocks, crumbling slowly, forming poor, thin soils, which rest on an impervious rock, and which, from the height to which this formation generally rises above the level of the sea, are rendered more unproductive by an unpropitious climate. They form extensive heathy tracts in Perth and Argyle, and on the north and west of Ireland. Here and there only—in the valleys or sheltered slopes, and by the margins of the lakes—spots of bright green meet the eye, and patches of a willing soil, fertile in corn.

SECTION IV.—GENERAL CONCLUSIONS AS TO THE RELATIONS OF GEOLOGY TO AGRICULTURE.

A careful perusal of the preceding sketch of the general agricultural capabilities of the soils formed from the several classes of stratified rocks, will have presented to the reader many illustrations of the facts stated in the previous chapter. He will have drawn for himself—to specify a few examples—the following among other conclusions :—

1. That some formations, like the new red sandstone, yield a soil almost always productive ; others, as the coal measures and millstone grits, a soil almost always *naturally* unproductive ; and others, again, like the mountain limestone, a short sweet herbage, grateful to cattle, and productive of butter and cheese.

2. That good—or better land, at least, than generally prevails in a district—may be expected where two formations, or two different kinds of rock, meet. As when a limestone and a clay mingle their mutual ruins for the formation of a common soil.*

* See diagram No. 5, p. 104.

3. That in almost every country extensive tracts of land, on certain formations, will be found laid down to natural grass, *in consequence of the original difficulty and expense of working*. Such are the Lias, the Oxford, the Weald, the Kimmeridge, and the London clays. In raising corn, it is natural that the lands which are easiest and cheapest worked should be first subjected to the plough. It is not till implements are improved, skill increased, capital accumulated, and population presses, that the heavier lands in a country are rescued from perennial grass, and made to produce that greatly increased amount of food for both man and beast, which they are easily capable of yielding.

4. That the rotations adopted in a district, though faulty, and, in the eyes of improved agriculture, deserving of condemnation, are often not only determined, but rendered necessary by the natural structure of the country. When cold clays refuse to bear even average crops of any other kinds than wheat and beans, the old European rotation of wheat, beans, fallow—which in this country has prevailed, in many places, since the times of the ancient Britons—becomes almost a necessity to the farmer. It is unfair to blame his rotations, or accuse him of prejudice and ignorance in clinging to them, till the natural condition of the land has been altered by art, so as to fit it for the profitable growth of other crops.

The turnip and barley soils of Great Britain are in many districts, it may be, but indifferently farmed; and the State has reason to complain of much individual neglect of known and certain methods of increasing their productiveness. But *the great achievement which British agriculture has now to effect, is to subdue the stubborn clays, and to convert them into, what many of them are*

yet destined to become, the richest corn and green-crop bearing lands in the kingdom.

5. That there are larger tracts of country still—such as rest on the slates of the Lower Silurian and Cambrian systems, for example—from which the efforts of the enlightened agriculturist have hitherto been withheld, in consequence of the apparent hopelessness of ever bringing them into profitable culture. Over these tracts, however, there are large portions which will pay well for skilful improvement. Make roads and drains, bring in lime, and manure well. You will thus improve the soil, gradually ameliorate the climate, make modern skill and improvements available, obtain a remunerating return for labour economically expended, and for capital judiciously invested, and you will at the same time increase the power and the resources of the country.

CHAPTER VIII.

Poor soils of the granites and fertile soils of the trap rocks, and of the modern lavas.—Composition of felspar and hornblende.—Accumulations of transported sands, gravels, and clays.—Their influence on agricultural capability.—Illustration from the neighbourhood of Durham.—Importance of surface or drift geology to agriculture.—General uniformity in the agricultural character of the rocks and soils on geological formations of the same age.—Exceptions among the Silurian rocks.—Use of geological maps in reference to agriculture.

It was stated in a preceding chapter that rocks are divided by geologists into the stratified and the *unstratified.** The stratified rocks cover by far the largest portion of the globe, and form the great variety of soils, of which a general description has just been given. The unstratified rocks are of two kinds—the *granites* and the *trap* rocks; and as a considerable portion of the area, especially of the northern half, of our island is covered by them, it will be proper shortly to consider the peculiar characters of each, and the differences of the soils produced from them.

SECTION I.—POOR SOILS OF THE GRANITES, AND FERTILE SOILS OF THE TRAP ROCKS AND MODERN LAVAS.

1. The *Granites* consist of a mixture, in different proportions, of three minerals, known by the names of

* The unstratified are often called *crystalline* rocks, because they frequently have a glassy appearance, or contain regular crystals of cer-

quartz, *felspar*, and *mica*. The latter, however, is generally present in such small quantity, that in our general description it may be safely left out of view. Granites, therefore, consist chiefly of quartz and felspar, in proportions which vary very much ; but the former, on an average, constitutes perhaps from one-third to one-half of the whole.

Quartz has already been described as being the same substance as flint, or the silica of the chemist. When the granite decays, this portion of it forms a more or less coarse silicious sand.

Felspar is a white, greenish, or flesh-coloured mineral, often more or less earthy in its appearance, but generally hard and brittle, and sometimes glassy. It is scratched by quartz, and thus is readily distinguished from it. When felspar decays, it forms an exceedingly fine tenacious clay, (pipe-clay.)

Granite generally forms hills, and sometimes entire ridges of mountains. When it decays, the rains and streams wash out the fine felspar clay, and carry it down into the valleys, leaving the quartz sand on the sides of the hills. Hence the soil in the bottoms and flats of granite countries consists of a cold, stiff, wet, more or less impervious clay, which, though capable of much improvement by draining, often bears only heath, bog, or a poor and un-nutritive pasture. The hill sides are either bare, or are covered with a thin, sandy, and ungrateful soil, of which little can be made without the application of much skill and industry. Yet the opposite sides of the same mountains often present a remarkable difference in this respect ; those which are most beaten by the rains

tain mineral substances ; often also *igneous* rocks, because they appear all to have been originally in a melted state, or to have been produced by fire.

having the light clay most thoroughly washed from their surfaces, and being therefore the most sandy and barren.

2. The *Trap* rocks, comprising the green-stones and basalts—both sometimes called *whin*-stones—consist essentially* of felspar and *hornblende* or *augite*. In contrasting the trap rocks with the granites, it may be stated *generally*, that while the granites consist of felspar and *quartz*, the traps consist of felspar and *hornblende* (or augite.) In the traps, both the felspar and the hornblende are reduced, by the action of the weather, to a more or less fine powder, affording materials for a soil; in the granites, the felspar is the principal source of the fine earthy matter they are capable of yielding. If we compare together, therefore, the chemical composition of the two minerals, (hornblende and felspar,) we shall see in what respect these two varieties of soil ought principally to differ. Thus they consist respectively of—

	Felspar.	Hornblende.
Silica, ...	65	42
Alumina, . . .	18	14
Potash and soda, . .	17	trace.
Lime, ...	trace.	12
Magnesia, . . .	do.	14
Oxide of iron, . . .	do.	14¼
Oxide of manganese, . .	do.	½
	100	97

A remarkable difference appears thus to exist, in chemical composition, between these two minerals—a difference which must affect also the soils produced from them. A *granite* soil, in addition to the silicious sand, will consist chiefly of silica, alumina, and potash, derived from the felspar. A *trap* soil, in addition to the silica, alumina, and potash from its felspar, will generally con-

* The reader is referred for more *precise* information to the Author's "LECTURES," 2d edition, pp. 483 to 498.

tain also much lime, magnesia, and oxide of iron, derived from its hornblende. If the variety of trap consist chiefly of hornblende, as is sometimes the case, the soil formed from it will derive nearly 2½ cwt. each of lime, magnesia, and oxide of iron, from every ton of decayed rock. A hornblende soil, therefore, contains a greater number of those inorganic substances which plants require for their healthy sustenance, and, therefore, will prove more generally productive than a soil of decayed felspar. But when the two minerals, hornblende and felspar, are mixed together, as they are in the variety of trap called green-stone, the soil formed from them must be still more favourable to vegetable life. The potash and soda, of which the hornblende is nearly destitute, is abundantly supplied by the felspar; while the hornblende yields lime and magnesia, which are known to exercise a remarkable influence on the progress of vegetation.

This chemical knowledge of the nature and differences of the rocks from which the granite and trap soils are derived, explains several interesting practical observations. Thus it shows—

a. That while granite soils, in their natural state, may be eminently unfruitful, trap soils may be eminently fertile; and such is actually the result of observation and experience in every part of the globe. *Unproductive* granite soils cover nearly the whole of Scotland north of the Grampians, as well as large tracts of land in Devon and Cornwall, and on the east and west of Ireland. On the other hand, *fertile* trap soils extend over thousands of square miles in the lowlands of Scotland, and in the north of Ireland; and where in Cornwall they occasionally mix with the granite soils, they are found to redeem the latter from their natural barrenness.

But while such is the *general* rule in regard to these

two classes of soils, it happens on some spots that the presence of other minerals in the granites, or of hornblende or mica in larger quantity than usual, gives rise to a granitic soil of average fertility, as is the case in the Scilly Isles. In like manner, the trap rocks are sometimes, as in parts of the Isle of Skye, so peculiar in their composition as to condemn the land to almost hopeless infertility.

b. Why in some districts the decayed traps, under the local names of *Rotten rock*, *Marl*, &c., are dug up, and applied with advantage, as a top-dressing, to other kinds of land. They afford supplies of lime, magnesia, &c., of which the soils they are found to benefit may be naturally deficient. And as, by admixture with the decayed trap, the granitic soils of Cornwall are known to be improved in quality, so an admixture of decayed granite with many trap soils, were it readily accessible, might add to the fertility of the latter also.

c. Why the application of lime in certain trap districts adds nothing to the fertility of the land. The late Mr Oliver of Lochend informed me that he had never known a case in which the application of lime within five miles of Edinburgh had done any good. This he accounted for from the vast number of oyster shells which are mixed with the town dung laid on by the Edinburgh farmers. Another important reason, however, is the abundance of lime contained in the trap rocks from which the soils are formed, and of which they contain so many fragments. A piece of decaying trap I lately picked up on the north side of the Pentland hills, on the farm of Swanstone, was found in my laboratory to contain as much as 16 per cent of carbonate of lime.

d. Why, as in many parts of the counties of Ayr and Fife, the application of lime is found to be useful when

the trap soils are first broken up or reclaimed, but to produce little sensible benefit for twenty or thirty years afterwards, however frequently applied. In these cases the lime has been washed out of the surface soil, and from the thoroughly decayed parts of the trap, so that, when first broken up, lime is necessary to supply the deficiency. But the constant turning up of the soil by the after-cultivation exposes fresh portions of trap to the air, the decay of which annually supplies a quantity of lime to the soil from the rocky fragments themselves, and renders further artificial applications less necessary. I have picked up a piece of decaying trap, of which the outer portion contained scarcely any lime, while the central kernel contained a large proportion. The plough and harrow break up such decaying masses, and expose the undecomposed kernels to the weathering action of the atmosphere, and to the roots of the growing crops.

3. The *Lavas* which often cover large tracts of country, where active or extinct volcanoes exist, are composed essentially of the same mineral substances as the trap rocks. These latter, indeed, are in general only lavas of a more ancient date. Like the traps, the lavas not unfrequently abound in hornblende or augite, and consequently in lime. They also crumble, with various degrees of rapidity, when exposed to the air, and in Italy and Sicily often form soils of the most fertile description. Like the traps also, when in a decayed state, they may be advantageously employed for the improvement of less fruitful soils. In St Michael's, one of the Azores, the natives pound the volcanic matter and spread it on the ground, where it speedily becomes a rich mould, capable of bearing luxuriant crops.

SECTION II.—OF THE SUPERFICIAL ACCUMULATIONS OF TRANSPORTED MATERIALS ON DIFFERENT PARTS OF THE EARTH'S SURFACE, AND THEIR RELATIONS TO THE SOIL.

It is necessary to guard the reader against disappointment when he proceeds to examine the relations which exist between the soils and the rocks on which they lie, or to infer the quality of the soil from the known nature of the rock on which it rests—in conformity with what has been above laid down—by explaining another class of geological appearances, which present themselves not only in our own country, but in almost every other part of the globe.

The unlearned reader of the preceding section and chapter may say—I know excellent land resting upon the granites, fine turnip soils on the Oxford or London clays, tracts of fertile fields on the coal measures, and poor gravelly farms on the boasted new red sandstone: I have no faith in theory—I can have none in theories which are so obviously contradicted by natural appearances. Such, it is to be feared, is the hasty mode of reasoning among too many locally* excellent practical men—familiar, it may be, with many useful and important facts, but untaught to look through and beyond isolated facts to the principles on which they depend.

Every one who has lived long on the more exposed shores of our island, has seen that, when the weather is

* By *locally* excellent, I mean those who are the best possible farmers on their own districts and after their own way, but who would fail in other districts requiring other methods. To the possessor of agricultural principles, the modifications required by difference of crop, soil, and climate, readily suggest themselves, where the mere practical man is bewildered, disheartened, and in despair.

dry, and the sea-winds blow strong, the sands of the beach are carried inland and spread over the soil, sometimes to a considerable distance from the coast. In some countries this sand-drift takes place to a very great extent, travels over a great stretch of country, and gradually swallows up large tracts of fertile land, and converts them into sandy deserts.

Again, most people are familiar with the fact, that during periods of long-continued rain, when the rivers are flooded and overflow their banks, they not unfrequently bear with them loads of sand and gravel, which they carry far and wide, and strew at intervals over the surface-soil.

So the annual overflowings of the Nile, the Ganges, the Mississippi, and the river of the Amazons, gradually deposit accumulations of soil over surfaces of great extent;—and so also the bottoms of most lakes are covered with thick beds of sand, gravel, and clay, which have been conveyed into them from the higher grounds by the rivers which flow into them. Over the bottom of the sea, also, the ruins of the land are spread. Torn by the waves from the crumbling shore, or carried down from great distances by the rivers which lose themselves in the sea, they form beds of mud, or banks of sand and gravel of great extent, which cover and conceal the rocks on which they lie.

To these and similar agencies, a large portion of the existing dry land of the globe has been, and is still, exposed. Hence, in many places, the rocks and the soils naturally derived from them are buried beneath accumulated heaps or layers of sand, gravel, and clay, which have been brought from a greater or less distance, and which have not unfrequently been derived from rocks of a totally different kind from those of the districts in which

they are now found. On these accumulations of *transported* materials, a soil is produced which often has no relation in its characters to the rocks which cover the country, and the nature of which soils, therefore, a familiar acquaintance with the rocks on which they immediately rest would not enable us to predict.

To this cause is due that discordance between the first indications of geology, as to the origin of soils from the rocks on which they rest, and the actually observed characters of those soils in certain districts—of which discordance mention has been made as likely to awaken doubt and distrust in the mind of the less instructed student, in regard to the predictions of agricultural geology. There are several circumstances, however, by which the careful observer is materially aided in endeavouring to understand what the nature of the soils is likely to be in any given district, and how they ought to be treated even when the subjacent rocks are thus overlaid by masses of drifted materials. Thus—

1. It not unfrequently happens that the materials brought from a distance are more or less mixed up with the fragments and decayed matter of the rocks which are native to the spot,—so that, though modified in quality, the soil nevertheless retains the general characters of that which is formed in other places from the decay of these rocks alone.

2. Where the formation is extensive, or covers a large area,—as the new red sandstones and coal measures do in this country, the mountain limestones in Ireland, and the granites in the north of Scotland,—the transported sand, gravel, or clay, strewed over one part of the formation, has not unfrequently been derived from the rocks of another part of the *same* formation; so that, after all, the soils may be said to be produced from the rocks on

which they rest, and may be judged of from the known composition of these rocks.

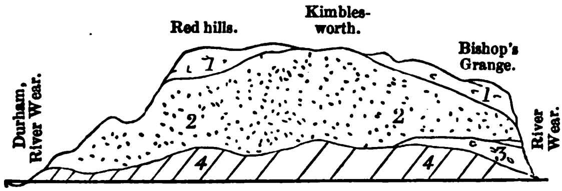
3. Or if not from the rocks of the same formation, they have most frequently been derived from those of a neighbouring formation—from rocks which are to be found at *no great distance geologically*, and generally on higher ground. Thus the ruins of the millstone-grit rocks are in this country often spread over the surface of the coal measures—of these, again, over the magnesian limestone—of the latter over the new red sandstone, and so on. The effect of this kind of transport of the loose materials upon the character of the soils is merely to overlap, as it were, the edges of one formation with the proper soils of the formations that adjoin it, in the particular direction from which the drifted materials are known to have come.

It appears, therefore, that the occurrence on certain spots, or tracts of country, of soils that have no apparent relation to the rocks on which they immediately rest, tends in no way to throw doubt upon, to discredit or to disprove, the conclusions drawn from the more general facts and principles of geology. It is still generally true that soils *are* derived from the rocks on which they rest. The exceptions are local, and the difficulties which these local exceptions present, require only from agricultural geologists a more careful study of the structure of each district—of the direction of the highlands—the nature of the slopes—the course and width of the valleys—and the extent of the plains,—before they pronounce a decided opinion as to the degree of fertility which the soil either naturally possesses, or by skilful cultivation may be made to attain.

It is not to be denied, however, that the practical importance of these local exceptions is becoming every day more manifest, and the necessity more apparent for a

careful recording, and mapping of them in the interests of agriculture. Riding over the country, for example, due north from the city of Durham, a distance of about three miles, till we are stopped by a bend of the river Wear, the superficial covering, so far as it can be seen, is represented by the subjoined section.

No. 7.



1. Yellow unstratified hard clay with small stones and boulders, forming cold impervious clay soils, 3 to 40 feet.

2. Yellow sand, loose, with fragments of drifted coal and sandstone gravel and boulders, forming potato, barley, and light turnip soils, 10 to 100 feet.

3. Blue unstratified clay, with boulders—often wanting —10 to 30 feet.

4. The coal measures lying beneath.

All the country being covered, as this section represents, with from 30 to 120 feet of superficial sands and clays, it is obvious that it can be of comparatively little use to me to know that the sandstones and shales of the coal measures lie far below; and though I know that the sands and clays are all derived from the crumbled beds of the coal measures, yet they give me no information respecting the sandy nature of the soils near Kimblesworth, or that they are cold and clayey about Bishop's Grange. The nature of the soil in each portion of the district—and the same is true of a large portion of the

county of Durham—depends upon whether the clay or the sand comes to the surface. This can only be shown upon special maps, rigorously prepared for the purpose; and these the progress of scientific agriculture will soon render indispensable.

SECTION III.—GENERAL UNIFORMITY IN THE AGRICULTURAL CHARACTER OF THE ROCKS AND SOILS ON GEOLOGICAL FORMATIONS OF THE SAME AGE.

And yet there is a wonderful degree of general uniformity in the mineral character and agricultural capabilities of the same geological formation in different countries, even when they lie at great distances from each other. I have already alluded, for example, in a preceding chapter,* to the natural dryness of the belt of chalk which runs along the Atlantic border of the United States. The scarcity of water experienced by those who reside upon it is often great. Every one knows that the same is true of our own chalk region in England, and that this very materially affects its agricultural capabilities. It is familiar to every one also, that in very many places wells are sunk through it with the view of reaching water, and that in London great depths are gone to, and at a vast expense, through the London clay and the chalk, before water can be obtained. In the Paris basin the chalk is equally dry; and there are very few who have not read of the remarkably deep well at Grenelle in the neighbourhood of Paris, which, like the less profound London wells, has been sunk to the sands below the chalk, and with similar success.

So, in the remote State of Alabama, on this formation, water is only to be obtained by sinking through the

* See the diagram in p. 100.

chalk; and there also this circumstance modifies in a wonderful degree the general dispositions of rural economy. Three years ago there were already about 500 wells in that State, sunk to a depth of from 400 to 600 feet, there being one generally upon each plantation. And thus, while the climate there, as elsewhere, determines the general character of the vegetable produce, and what kind of plants under the meteorological conditions can arrive at perfection, yet the geological structure determines, and enables us to judge beforehand, to a certain extent, whether or not any crops shall be able to grow at all, and of the kind of plants suitable to the climate, which can be profitably cultivated, under the circumstances of soil and dryness, which that geological structure implies.

I may here remark, that, in this case of Alabama, the geological structure determines more. In such a climate, and with a soil so naturally arid, abundant water is indispensable; but this can only be obtained by deep boring, performed at a great expense. The geological conditions, therefore, confine the possibility of cultivation to men of large means, and, in present circumstances at least, necessarily exclude all petty farming and the subdivision of the land into small holdings. They determine, in other words, the social condition of the people. This single illustration is enough of itself to satisfy any impartial person of the close general relation which exists between the geological character and the agricultural capability of a country, and of the broad general deductions in regard to its possible future prosperity—in a rural sense—which may be drawn from a knowledge of its geology. I believe it is partly under the influence of this conviction that the Senate and Congress of the

United States have so often and so cordially voted large sums of money for the purpose of investigating and mapping the main geological features of the new States and territories which from time to time have been admitted into the Union.

Geological *maps*, such as those now referred to, indicate with more or less precision the extent of country over which the chalk, the red sandstone, the granites, &c., are found immediately beneath the loose materials on the surface. Such maps, therefore, are of great value in indicating also the general quality of the soils over the same districts. It may be true, as I have above explained, that here and there the *natural* soils are masked or buried by transported materials—yet the *political economist* may, nevertheless, with safety estimate the general agricultural capabilities and resources of a country by the study of its geological structure—the *capitalist* judge in what part of it he is likely to meet with an agreeable or profitable investment—and the *practical farmer* in what country he may expect to find land that will best reward his labours, that will admit of the kind of culture to which he is most accustomed, or, by the application of better methods, will manifest the greatest agricultural improvement.

There are many cases also in which geology, leaving the humbler task of explaining why certain regions exhibit, or are capable of exhibiting, singular natural fertility, or the reverse, advances to the higher gift of prediction. United theory and observation enable it not only to point out where rich and desirable lands are sure to be found—to inform the statesman as to the true value of regions still wild and neglected—to direct the agricultural emigrant in the choice of new homes—but looking

far into the future, to specify also the kind of population and the processes of industry which will hereafter prevail upon it—the comparative comfort, wealth, numbers, and even morality, of its future people.

That there are certain cases in which geology finds herself at fault, or her general deductions unsupported by the reality, is only a proof that it is a part of human science, rapidly progressive, but still full of imperfections.

CHAPTER IX.

Of the physical, chemical, and botanical relations of soils.—Physical properties.—Density, absorbent, and evaporative powers, capillary action, shrinkage, absorption of moisture from the air, and of heat from the sun.—Functions of soils in reference to vegetation.—Chemical composition and analysis of soils.—Comparative composition of certain fertile and barren soils.—Importance of certain forms of organic matter to the fertility of a soil.—The black earth of central Russia.—Direct relation between the character of the soil and the kind of plants that naturally grow upon it.

Soils formed, as we have described, from the ruins of crumbled rocks, more or less sorted and drifted by water, possess three classes of properties, intimately related to each other, and to their special agricultural value. These are their *physical*, *chemical*, and *botanical* properties. A brief consideration of these will form the subject of the present chapter.

SECTION I.—OF THE PHYSICAL PROPERTIES OF SOILS.

1°. *Density.*—Some soils are heavier and denser than others, sands and marls weighing most, and dry peaty soils the least. This density is of so much practical importance, that treading with sheep and other stock is resorted to in many districts, with the view of rendering the land more solid; or heavy rollers are passed over it, to prepare a firm seed-bed for the corn. Also, in reclaiming peaty soils, it is found highly beneficial to increase their

density by a covering of clay or sand, or, as in Ireland, of limestone gravel.

2°. *Absorption of water.*—Again, some soils absorb the rains that fall, and retain them in larger quantity and for a longer period than others. Strong clays absorb and retain nearly three times as much water as sandy soils do, while peaty soils absorb a still larger proportion. Hence the more frequent necessity for draining clayey than sandy soils; and hence also the reason why, in peaty land, the drains must be kept carefully open, in order that the access of springs and of other water from beneath may be as much as possible prevented.

3°. The *capillary action* of soils also differs. Some, when immersed in water, will become moist, or attract the water upwards for 10 or 12 inches, some as many as 16 or 18 inches, above the surface of the water. This property is of great importance in reference to the growth of plants—to the rising of water to the surface of land which rests upon a wet subsoil—to the necessity for thorough drainage—to the general warmth of the soil, and so on.

4°. *Evaporative power.*—When dry weather comes, soils lose water by evaporation with different degrees of rapidity. In this way a silicious sand will give off the same weight of water, in the form of vapour, in one-third of the time necessary to evaporate it from a stiff clay, a peat, or a rich garden mould, when all are equally exposed to the air. Hence the reason why plants are so soon burned up in a sandy soil. Not only do such soils *retain* less of the rain that falls, but that which is retained is also more speedily dissipated by evaporation. When rains abound, however, or in very moist seasons, these same properties of sandy soils enable them to dry quickly, and thus to sustain a luxuriant vegetation at a

time when plants will perish on clay lands from excess of moisture.

5°. *Shrinkage.*—In drying under the influence of the sun, soils shrink in, and thus diminish in bulk, in proportion to the quantity of clay or of peaty matter they contain. Sand scarcely diminishes at all in bulk by drying, but peat shrinks one-fifth in bulk, and strong agricultural clay nearly as much. The roots are thus compressed and the air excluded from them, especially in the hardened clays, in very dry weather, and thus the plant is placed in a condition unfavourable to its growth. Hence the value of proper admixtures of sand and clay. By the latter (the clay) a sufficient quantity of moisture is retained, and for a sufficient length of time; while by the former the roots are preserved from compression, and a free access of the air is permitted.

6°. *Absorption of moisture from the air.*—In the hottest and most drying weather, the soil has seasons of respite from the scorching influence of the sun. During the cooler season of the night, even when no perceptible dew falls, it has the power of again extracting from the air a portion of the moisture it had lost during the day. Perfectly pure sand possesses this power in the least degree; it absorbs little or no moisture from the air. *A stiff clay,* on the other hand, *will, in a single night, absorb sometimes a 30th part of its own weight, and a dry peat as much as a 12th of its weight;* and, generally, the quantity thus drunk in, by soils of various qualities, is dependent upon the proportions of clay and vegetable matter they severally contain. We cannot fail to perceive from these facts, how much the productive capabilities of a soil are dependent upon the proportions in which its different earthy and vegetable constituents are mixed together.

7°. *The temperature of a soil,* or the degree of warmth it

is capable of attaining under the influence of the sun's rays, materially affects the progress of vegetation. Every gardener knows how much *bottom* heat forces the growth, especially of young plants; and wherever a natural warmth exists in the soil, independent of the sun, as in the neighbourhood of volcanoes, there it exhibits the most exuberant fertility. One main influence of the sun in spring and summer is dependent upon its power of thus warming the soil around the young roots, and rendering it propitious to their rapid growth. But the sun does not warm all soils alike—some become much hotter than others, though exposed to the same sunshine. When the temperature of the air in the shade is no higher than 60° or 70°, a *dry* soil may become so warm as to raise the thermometer to 90° or 100°. Mrs Ellis states, that among the Pyrenees the rocks actually smoke after rain, under the influence of the summer sun, and become so hot that you cannot sit down upon them. In Central Australia, where the thermometer is sometimes as high as 132° F. in the shade, and 157° in the sunshine, the ground becomes so hot that it kindles matches that fall on it, and burns the skin off the dog's feet. In *wet* soils the temperature rises more slowly, and rarely attains the same height as in a dry soil by 10° or 15°. Hence it is strictly correct to say, that wet soils are *cold;* and it is easy to understand how this coldness is removed by perfect drainage.* Dry sands and clays, and blackish garden mould, become warmed to nearly an equal degree under the same sun; brownish-red soils are heated somewhat more, and dark-coloured peaty soils the most of all. It is probable, therefore, that the presence of dark-coloured vegetable matter renders the soil more absorbent of heat from the sun, and that the colour of the dark-red marls

* See the succeeding Chapter.

of the new and old red sandstones may, in some degree, aid the other causes of fertility in the soils which they produce.

In reading the above observations, the practical reader can hardly fail to have been struck with the remarkable similarity in physical properties between stiff clay and peaty soils. Both retain much of the water that falls in rain, and both part with it slowly by evaporation. Both contract much in drying, and both absorb moisture readily from the air, in the absence of the sun. In this similarity of properties we see not only why the first steps in improving both kinds of soil must be very nearly the same, but why, also, a mixture either of clay or of vegetable matter will equally impart to a sandy soil many of those elements of fertility—of which they are alike possessed.

SECTION II.—OF THE CHEMICAL COMPOSITION AND ANALYSIS OF SOILS.

Soils perform at least three functions in reference to vegetation. They serve as a basis in which plants may fix their roots and sustain themselves in their erect position—they supply food to vegetables at every period of their growth—and they are the medium in which many chemical changes take place, that are essential to a right preparation of the various kinds of food which the soil is destined to yield to the growing plant.

We have spoken of soils as consisting chiefly of sand, lime, and clay, with certain saline and organic substances in smaller and variable proportions. But the study of the ash of plants (see chap. iv.) shows us that a fertile soil, besides its organic matter, must of necessity contain an appreciable quantity of twelve or fourteen different mineral

substances, which, in most cases, exist in greater or less relative abundance in the ash both of wild and of cultivated plants.

Two well-known geological facts lead to precisely the same conclusion. We have seen that the soils formed from the unstratified rocks—the granites and the traps—while they each contain certain earthy substances in proportions peculiar to themselves, yet contain also in general, especially the trap soils, a *trace* of most of the other kinds of matter which are found in the ash of plants. Again, it is equally certain that the stratified rocks are only the more or less slowly accumulated fragments and ruins of more ancient stratified or unstratified masses, which, under various agencies, have gradually crumbled to dust, been strewed over the surface in alternate layers, and have afterwards again consolidated. The reader will readily grant, therefore, that in all rocks, and consequently in all soils, *traces* of every one of these substances may generally be presumed to exist.

Actual *chemical analysis* confirms these deductions in regard to the composition of soils. It shows that, in most soils, the presence of all the constituents of the ash of plants may be detected, though in very variable and sometimes in very minute proportions; and, following up its investigations in regard to the effect of this difference in their proportions, it establishes certain other points of the greatest possible importance to agricultural practice. Thus, it has found, for example—

1. That as a proper adjustment of the proportions of clay, sand, and vegetable matter, is necessary in order that a soil may possess the most favourable *physical* properties, so the mere presence of the various kinds of food, organic and inorganic, in a soil, is not sufficient to make it productive of a given crop, but that they must be pre-

sent in such quantity that the plant shall be able readily—at the proper season, and within the time usually allotted to its growth—to obtain an adequate supply of each.

Thus a soil may contain, on the whole, far more of a given ingredient, such as potash, soda, and lime, than the crop we have sown may require, and yet, being diffused through a large quantity of earth, the roots may be unable to collect this substance fast enough to supply the wants of a rapidly growing plant. To such a soil it will be necessary to add a further portion of what the crop requires.

Again, a crop of winter wheat, which remains nine or ten months in the field, has much more leisure to collect from the soils those substances which are necessary to its growth than a crop of barley, which in cold climates like that of Sweden is only from 6 to 7½ weeks in the soil, and which in warm countries like Sicily may be reaped twice in the year. Thus a soil which refuses to yield a good crop of the quick-growing barley may readily nourish a crop of slow-growing wheat.

2. That when a soil is particularly poor in certain of these substances, the valuable cultivated corn crops, grasses, and trees, refuse to grow upon them in a healthy manner, and to yield remunerating returns. And,

3. That when certain other substances are present in too great abundance, the soil is rendered equally unpropitious to the most important crops.

In these facts the intelligent reader will perceive the foundation of the varied applications to the soil which are everywhere made under the direction of a skilful practice—and of the difficulties which, in many localities, lie in the way of bringing the land into such a state as shall fit it readily to supply all the wants of those kinds

of vegetables which it is the special object of artificial culture easily and abundantly to raise.

Chemical analysis is a difficult art—one which demands much chemical knowledge, as well as skill in chemical practice, (manipulation, as it is called,) and calls for both time and perseverance—if valuable, trustworthy, and minutely correct results are to be obtained. I believe it is only by aiming after such minutely correct results that chemical analysis is likely to throw light on the peculiar properties of those soils which, while they possess much general similarity in composition and physical properties, are yet found in practice to possess very different agricultural capabilities. Many such cases occur in every country, and they present the kind of difficulties in regard to which agriculture has a right to say to chemistry—"These are matters which I hope and expect you will satisfactorily clear up." But while agriculture has a right to use such language, she has herself preliminary duties to perform. She has no right in one breath to deny the value of chemical theory to agricultural practice, and in another to ask the sacrifice of time and labour in doing her chemical work. Chemistry is a wide field, and many zealous lives are now being spent in the prosecution of it, without at all entering upon the domain of practical agriculture. It may be that here and there it may fall in with the humour or natural bias of some one chemist to apply his knowledge to this most important art; but hitherto the appreciation of such efforts has, except by a limited few, been so small—the reception of scientific results and suggestions by the agricultural body generally so ungracious—that little wonder can exist that so many chemists have quitted the field in disgust—that the majority of capable men should studiously avoid it.

SECTION III.—COMPARATIVE COMPOSITION OF FERTILE AND BARREN SOILS.

With the view of illustrating the deductions which, as above stated, may be drawn from an accurate chemical analysis, I shall exhibit the composition of three different soils, as determined by Sprengel, a German agricultural chemist.

No. 1 is a very fertile alluvial soil from East Friesland, formerly overflowed by the sea, but for sixty years cultivated with corn and pulse crops *without manure.*

No. 2 is a fertile soil near Göttingen, which produces excellent crops of clover, pulse, rape, potatoes, and turnips, the two last more especially *when manured with gypsum.*

No. 3 is a very barren soil from Luneberg.

When washed with water in the manner described in page 83, they give respectively, from 1000 parts of soil—

	No. 1.	No. 2.	No. 3.
Soluble saline matter, ...	18	1	1
Fine clay and organic matter, .	937	839	599
Silicious sand, ...	45	160	400
	1000	1000	1000

The most striking distinction presented by these numbers is the large quantity of saline matter in No. 1. This soluble matter consisted of common salt, chloride of potassium, sulphate of potash, and sulphate of lime, (gypsum,) with traces of sulphate of magnesia, sulphate of iron, and phosphate of soda. The presence of this comparatively large quantity of these different saline substances—originally derived, no doubt, in great part from the sea—was probably one reason why it could be so long cropped without manure.

The unfruitful soil is much the lightest (in the agricultural sense) of the three, containing 40 per cent of sand; but this is not enough to account for its barrenness, many light soils containing a larger proportion of sand, and yet being sufficiently fertile.

The finer portions, separated from the sand and soluble matter, consisted, in 1000 parts, of—

	No. 1.	No. 2.	No. 3.
Organic matter,	97	50	40
Silica,	648	833	778
Alumina,	57	51	91
Lime,	59	18	4
Magnesia,	8½	8	1
Oxide of iron,	61	30	81
Oxide of manganese,	1	3	½
Potash,	2	trace.	trace.
Soda,	4	do.	do.
Ammonia,	trace.	do.	do.
Chlorine,	2	do.	do.
Sulphuric acid,	2	¾	do.
Phosphoric acid,	4½	1¾	do.
Carbonic acid,	40	4½	do.
Loss,	14	—	4½
	1000	1000	1000

1. The composition of No. 1 illustrates the first of the general deductions stated in the preceding section—that a considerable supply, namely, of *all* the species of inorganic food is necessary to render a soil eminently fertile. Not only does this soil contain a comparatively large quantity of soluble saline matter, but it contains also nearly 10 per cent of organic matter, and what, in connection with this, is of great importance, nearly 6 per cent of lime. The potash and soda, and the several acids, are also present in sufficient abundance.

2. In the second—a fertile soil, but one which *cannot dispense with manure*—there is little soluble saline matter, and in the insoluble portion we see that there are mere *traces* only of potash, soda, and the important acids. It con-

tains also only 5 per cent of organic matter, and less than 2 per cent of lime; which smaller proportions, together with the deficiencies above stated, remove this soil from the most *naturally* fertile class to that class which is susceptible, in hands of ordinary skill, of being *brought to*, and *kept in*, a very productive condition.

3. In the fine part of the third soil, we observe that there are many more substances deficient than in No. 2. The organic matter amounts apparently to 4 per cent, and there seems to be nearly half a per cent of lime. But it will be recollected that this soil contains 40 per cent of sand, (p. 138;) or that in every hundred of soil there are only 60 of the fine matter, of which the composition is presented in the table;—or 100 lb. of the native soil contain only 2½ lb. of organic matter and ¼ lb. of lime.

But all these *wants* would not alone condemn the soil to hopeless barrenness, because, in favourable circumstances, they might all be supplied by art. But the oxide of iron amounts to 8 per cent of this fine part of the soil; a proportion of this substance which, in a soil containing so little lime and organic matter, appears, from practical experience, to be incompatible with the healthy growth of cultivated crops. This soil, therefore, requires, not only those substances of which it is destitute, but such other substances also, or such a form of treatment, as shall prevent the injurious effects of the large portion of oxide of iron it contains.

In these three soils, therefore, we have examples, *first*, of one which contains within itself all the elements of fertility; *second*, of a soil which is destitute, or nearly so, of certain substances required by plants, which, however, can be readily added by the ordinary manures in general use, and to which the elements of gypsum are especially useful, in aiding it to feed the potato and the turnip; and

third, of a soil not only poor in many of the necessary species of the inorganic food of plants, but too rich in one (oxide of iron) which, when present in excess, is usually prejudicial to vegetable life.

This illustration, therefore, will aid the general reader in comprehending how far rigid chemical analysis is fitted to throw light upon the capabilities of soils, and to *direct* agricultural practice.

SECTION IV. — IMPORTANCE OF CERTAIN FORMS AND QUANTITIES OF ORGANIC MATTER TO THE FERTILITY OF A SOIL.

The black earth of Russia.—The *Tchornoi Zem*, or black earth of Central Russia, illustrates, in a very striking manner, the fact, that the *kind* and *quantity* of the organic matter which a soil contains are scarcely less influential upon its fertility than the mineral constituents to which, in the last section, I principally adverted. This remarkable black soil, "the finest in Russia, whether for the production of wheat or grass," covers an area of upwards of 60,000 square geographical miles, and is said to be everywhere of extreme and of nearly uniform fertility. It nourishes a population of more than twenty millions of souls, and yet annually exports upwards of fifty millions of bushels of corn. This black earth stretches into Hungary, and forms the largest extent of fertile soil possessing common and uniform qualities which is anywhere known to exist. Its origin and chemical composition, therefore, have naturally engaged the attention both of scientific and of practical observers.

Its depth varies from 1 or 2 to 20 feet; when moist, it is jet black, and when dry, of a dark brown. This dark colour, from which it derives its name, is due to the

presence of organic, chiefly vegetable matter, in a peculiar decomposed state, minutely divided and intimately mixed with mineral matter. Of the weight of the dry soil, it forms, in different samples, from 6 to 18 per cent. This vegetable matter is distinguished by two circumstances.

1. That it is in an exceedingly minute state of division, and is intimately mixed with finely-divided mineral matter. The black earth, therefore, forms a comparatively free and open soil, into which the air penetrates and the roots of plants descend freely.

2. It contains in a state of combination a considerable proportion of nitrogen. In different samples this constituent has been found to vary from 2½ (Payen) to 8 per cent (Schmidt) of the weight of the organic matter. Through the action of the air, this nitrogen will favour the production in the soil of nitric acid, ammonia, and other soluble compounds containing nitrogen, which I have already described as propitious to the growth of plants.

But in this black earth the composition of the mineral or inorganic part is also such as to promote fertility. In one of the richest varieties, in which the organic matter amounted to 18 per cent, the mineral matter was found to consist of—

	Per cent.
Potash,	5.81
Soda,	2.31
Lime,	2.60
Magnesia,	0.95
Alumina and oxide of iron, with traces of phosphoric acid,	17.32
Silica, of which 7 or 8 per cent were soluble,	70.94
	99.93

We see in this analysis an abundant supply of those mineral substances which appear to be so necessary to the healthy growth of plants.

The general results of our analytical examination of soils, therefore, are chiefly these—

a. That a due admixture of organic matter is favourable to the fertility of a soil.

b. That this organic matter will prove the more valuable in proportion to the quantity of nitrogen it holds in combination.

c. That the mineral part of the soil must contain all those substances which are met with in the ash of the plant, and in such a state of chemical combination that the roots of plants can readily take them up in the requisite proportion.

It is to the long accumulation of the remains of forests, or other abundant ancient vegetation, that the colour of the Black earth, and its richness in organic matter, is, with the greatest probability, ascribed.

SECTION V.—OF THE DIRECT RELATION THAT EXISTS BETWEEN THE CHARACTER OF THE SOIL AND THE KIND OF PLANTS THAT NATURALLY GROW UPON IT.

The importance of a minute study of the chemical composition of soils will, perhaps, be most readily appreciated by a glance at the very different kinds of vegetables which, under the same circumstances, different soils naturally produce; in other words, by a glance at their botanical relations.

There are none so little skilled in regard to the capabilities of the soil, as not to be aware that some lands naturally produce abundant herbage or rich crops, while others refuse to yield a nourishing pasture, and are deaf to the often-repeated solicitations of the diligent husbandman. There exists, therefore, a universally understood connection between the kind of soil and the kind of

plants that naturally grow upon it. It is interesting to observe how close this relation in many cases is.

1. The sands of the sea-shore, the margins of salt lakes, and the surfaces of salt plains, like the Russian steppes, are distinguished by their peculiar tribes of salt-loving plants—by varieties of salsola, salicornia, &c. The *Triticum junceum* (sea wheat) grows on the seaward slopes of the downs at no great distance from the sea. The drifted sands more removed from the beach produce their own long, waving, coarser grass,—the *Arundo arenaria*, (sea bent,) the *Elymus arenarius*, (sea lime grass,) and the *Carex arenarius*, (sand sedge,) the roots of which plants bind the shifting sands together. The beautiful sea pink spreads itself over the loose downs—while further inland, and as the soil changes, new vegetable races appear.

2. The peaty hills and flats of our island naturally clothe themselves with the common ling, (*Calluna vulgaris*,) the fine-leaved heath, (*Erica cinerea*,) and with the cross-leaved heath, (*Erica tetralix*.) When drained and laid down to grass, or when they exist as natural meadows, they produce one soft woolly grass almost exclusively—the *Holcus lanatus*. After they are limed, these same soils become propitious to green crops and produce much straw, but refuse to fill the ear. The grain is thick-skinned, and therefore light in flour. There is a greater tendency to produce cellular fibre, and the insoluble matter associated with it, than the more useful substances starch and gluten.

3. On the margins of water-courses in which silica abounds, the mare's tail (*Equisetum*) springs up in abundance; while, if the stream contain much carbonate of lime, the water-cress appears and lines the sides and bottom of its shallow bed, sometimes for many miles from its source.

4. The Cornish heath (*Erica vagans*) shows itself rarely above any other than the serpentine rocks; the red broom-rape, (*Orobanche rubra,*) only on trap or basaltic rocks; the *Anemone pulsatilla* on the dry banks of chalky mounds, as in the neighbourhood of Newmarket; the lady's slipper on calcareous formations only; the *Medicago lupulina* on soils which abound in marl; while the red clover and the vetch delight in the presence of gypsum, and the white clover in that of alkaline matter in the soil.

So the red and white fire-weeds, *Epilobium coloratum*, and *Erichtites hierecifolius*, cover with their bright blossoms every open space in the North American woods, over which the fires, so frequent there, have run during the previous year. The ashes of the burned trees and underwood are specially grateful to the seeds of these plants, which in vast quantities lie dormant in the soils.

5. The clays, too, have their likings. The Rest harrow, (*Ononis arvensis,*) delights in the weald, the gault, and the plastic clays, but passes by the green sand and chalk soils, by which these clays are separated from each other. The oak, in like manner, characterises the clays of the weald; while the elm flourishes, in preference, on the neighbouring soils of the green-sand formation.

6. Then, again, plants seem to alternate with each other on the same soil. Burn down a forest of pines in Sweden, and one of birch takes its place *for a while.* The pines after a time again spring up, and ultimately supersede the birch. The same takes place naturally. On the shores of the Rhine are seen ancient forests of oak from two to four centuries old, gradually giving place at present to a natural growth of beech, and others where the pine is succeeding to both. In the Palatinate, the ancient oak-woods are followed by natural pines; and in

the Jura, the Tyrol, and Bohemia, the pine alternates with the beech.

These and other similar differences are believed to depend in great part upon the chemical composition of the soil. The slug may live well upon, and therefore infest, a field almost deficient in lime; the common land snail will abound at the roots of the hedges only where lime is plentiful, and can easily be obtained for the construction of its shell. So it is with plants. Each grows spontaneously where its wants can be most fully and most easily supplied. If they cannot move from place to place like the living animal, yet their seeds can lie dormant, until either the hand of man or the operation of natural causes produces such a change in their position, in reference to light, heat, &c., as to give them an opportunity of growing—or in the composition and physical qualities of the soil itself, as to fit it for ministering to their most important wants.

And such changes do naturally come over the soil. The oak, after thriving for long generations on a particular spot, gradually sickens; its entire race dies out, and other races succeed it. Has the operation of natural causes gradually removed from the soil that which favoured the oak, and introduced or given the predominance to those substances which favour the beech or the pine? On the light soils of the state of New Jersey the peach tree used to thrive better than anything else, and large sums of money were made from the peach grounds in that state. But of late years they have almost entirely failed. In Scotland, the Scotch fir has been known at once to die out over an area of 500 or 600 acres—and the forests of larch are now in many localities exhibiting a similar decay. This decay is often, I believe, owing to the presence of noxious matters in the subsoil, but it is due in some cases

also to a natural change in the composition and character of the several soils, which has taken place since the peach, the fir, and the larch trees were first planted upon them.

In the hands of the farmer, the land grows sick of this crop—it becomes tired of that. These facts may be regarded as indications of a change in the chemical composition of the soil. This alteration may proceed slowly and for many years; and the same crops may still grow upon it for a succession of rotations. But at length the change is too great for the plant to bear; it sickens, yields an unhealthy crop, and ultimately refuses altogether to grow.

The plants we raise for food have similar likes and dislikes with those that are naturally produced. On some kinds of food they thrive; fed with others, they sicken or die. The soil must therefore be prepared for their special growth.

In an artificial rotation of crops we only follow nature. One kind of crop extracts from the soil a certain quantity of all the inorganic constituents of plants, but some of these in much larger proportions than others. A second kind of crop carries off, in preference, a large quantity of those substances of which the former had taken little; and thus it is clearly seen, both why an abundant manuring may so alter the composition of the soil as to enable it to grow almost any crop; and why, at the same time, this soil may, in succession, yield more abundant crops, and in greater number, if the kind of plants sown and reaped be so varied as to extract from the soil, one after the other, the several different substances which the manure we have originally added is known to contain.

So with regard to the organic matter which soils contain. That form of organic food which suits one, may

not equally favour another species of plant, and thus, at different times, different species may be most suited to the chemical condition of the same field.

The management and tilling of the soil, in fact, is a branch of practical chemistry which, like the art of dyeing, of lead-smelting, or of glass-making, may advance to a certain degree of perfection without the aid of pure science, but which can only have its processes explained, and be led on to shorter, more simple, more economical, and more perfect processes, by the aid of scientific principles.

CHAPTER X.

Of the general improvement of the soil, and how the prudent man will commence such improvement.—Mechanical methods of improving the soil.—Draining, cause of the benefits produced by it.—Draining of apparently dry land.—Summary of the economical advantages of draining.—Depth to which drains ought to be dug.—Effects produced by the rains as they descend through the soil.

THE soil, in its natural condition, is possessed of certain existing and obvious qualities, and of certain other dormant capabilities. How are the existing qualities to be improved,—the dormant capabilities to be awakened?

SECTION I.—OF THE GENERAL IMPROVEMENT OF THE SOIL, AND HOW THE PRUDENT MAN WILL COMMENCE SUCH IMPROVEMENT.

There are few soils to which something may not still be done in the way of improvement, while by far the greatest breadth of the land, in almost every country, is still susceptible of extensive amelioration. In its present condition, the art of cultivating the land in England generally, differs from nearly all other arts practised among us in this—that he who undertakes it later in life, who brings to it a mind already matured, a good ordinary education, a sound judgment, and a fair share of prudence, who turns to it as a new pursuit, is often seen to take the lead among the agriculturists of the dis-

trict in which he settles. He comes to the occupation free from the trammels of old customs, old methods, and old prejudices, and hence, is free to adopt a sounder practice and more rational methods of cultivation. Such men, from lack of prudence or other causes, have not always prospered in their worldly affairs, but they have in very many districts been the beginners of agricultural improvements, the introducers of better systems of culture, and consequently public benefactors to the country.

What ought to be the course of such a man in embarking any serious amount of capital in this new pursuit? What that of an intelligent practical farmer on establishing himself in a new district?

Suppose them to be equally well read in the theory and in the general practice of agriculture, they will—

1. Examine the quality of the land, its soil and its subsoil, the exposure and the climate, the access to markets and to manures; and, generally, they will inquire what, in that district, are the more common sources of disappointment to the industrious farmer.

2. Consider what, in the abstract, theory would indicate as the most proper treatment for such land so situated, and the amount of produce it ought to yield.

3. Inquire what is the actual produce of the land, what the actual practice in the district, and especially the cause or reason of any local peculiarities in the practice which may be found to prevail. There are often good reasons for local peculiarities which new settlers injure themselves by overlooking, and find out too late for their own interest. The prudent man may look with suspicion upon such local customs, but he will be satisfied that there is no sufficient reason for their adoption, before he finally reject them to follow the indications of theory alone.

In illustration of this I may mention, that a friend of mine in Ayrshire, in agreeing to become the tenant of a farm which appeared to have been exhausted by the previous occupant, founded his hopes of success on ploughing deeper, and thus bringing a new soil to the surface, and his anticipations have not been disappointed by the result. On the other hand, I know of an instance in Berkshire, where, under the direction of a new agent, deeper ploughing was introduced, and the crops proved in consequence almost an entire failure. In this case sound theory indicated a deeper ploughing, but local experience had proved that shallow ploughing alone could preserve the crops from the fatal ravages of insect tribes. The local custom here, therefore, was founded upon a good reason, one sufficient to deter the prudent man from hasty or extensive experiments, though not enough to prevent him from seeking out some method of so extirpating the insect destroyers from his land, as to enable him afterwards to avail himself of its greater depth of soil.

Suppose it now to be determined that the land is capable of being made to yield a larger produce, the questions recur—what is the kind of improvement for which this land will give the best return? how is this improvement to be best, most fully, and at the same time most economically brought about?

All soils may be arranged into one or other of two classes.

1. Those which, like No. 1, (p. 139) contain in themselves an abundant supply of all those things which plants require, and are therefore fitted chemically to grow any crop.

2. Those which, like Nos. 2 and 3, (p. 139) are deficient in some of those substances on which plants live,

and are therefore not fitted to grow, perhaps, any one crop with luxuriance.

Both of these classes of soils, as they are naturally met with, are susceptible of improvement, the former by mechanical methods chiefly, the latter by mechanical partly, but chiefly by chemical methods. In the present chapter we shall consider the mechanical methods of improving the soil.

SECTION II.—OF IMPROVING THE SOIL BY DRAINING, AND THE CAUSES OF THE BENEFITS PRODUCED BY IT.

The first step to be taken in order to increase the fertility of nearly all the improvable lands of Great Britain, is to drain them. The advantages that result from draining are manifold.

1°. The presence of too much water in the soil keeps it constantly cold. The heat of the sun's rays, which is intended by nature to warm the land, is expended in evaporating the water from its surface; and thus the plants never experience that genial warmth about their roots which so much favours their rapid growth.

The temperature which a dry soil will attain in the summer time is often very great. Sir John Herschel observed, that at the Cape of Good Hope the soil attained a temperature of 150° Fahrenheit, when that of the air was only 120°; and Humboldt says, that the warmth of the soil between the tropics often rises to from 124° to 136°, (see p. 133.)

When the land is full of water, it is only after long droughts, and when it has been thoroughly baked by the sun, that it begins to attain the temperature which dry land under the same sun may have reached, day after day, probably for weeks before.

2°. Where too much water is present in the soil, also, that portion of the food of the plant which the soil supplies is so much diluted, that either a much greater quantity of fluid must be taken in by the roots—much more work done by them, that is—or the plant will be scantily nourished. The presence of so much water in the stem and leaves keeps down *their* temperature also, when the sunshine appears—an increased evaporation takes place from their surfaces—a lower natural heat, in consequence, prevails in the interior of the plant, and the chemical changes, on which its growth depends, proceed with less rapidity.

3°. By the removal of the water, the physical properties of the soil, also, are in a remarkable degree improved. Dry pipe-clay can be easily reduced to a fine powder, but it naturally, and of its own accord, runs together when water is poured upon it. So it is with clays in the field. When wet, they are close, compact, and adhesive, and exclude the air from the roots of the growing plant. But remove the water and they gradually contract, crack in every direction, become thus open, friable, and mellow, more easily and cheaply worked, and pervious to the air in every direction.

4°. The access of this air is essential to the fertility of the soil, and to the healthy growth of most of our cultivated crops. The insertion of drains not only makes room for the air to enter by removing the water, but actually compels the air to penetrate into the under parts of the soil, and renews it at every successive fall of rain. Open such outlets for the water below, and as this water sinks and trickles away, it will *suck* the air after it, and draw it into the pores of the soil wherever itself has been.

Vegetable matter becomes of double value in a soil

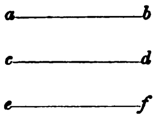
thus dried and filled with atmospheric air. When drenched with water, this vegetable matter either decomposes very slowly, or produces acid compounds more or less unwholesome to the plant, and even exerts injurious chemical reactions upon the earthy and saline constituents of the soil. In the presence of air, on the contrary, this vegetable matter decomposes rapidly, produces carbonic acid in large quantity, as well as other compounds on which the plant can live, and even renders the inorganic constituents of the soil more fitted to enter the roots, and thus to supply more rapidly what the several parts of the plant require. Hence, on dry land, manures containing organic matter, (farm-yard manure, &c.,) go farther or are more profitable to the farmer.

5°. Nor is it only stiff and clayey soils to which draining can with advantage be applied. It will be obvious to every one, that when springs rise to the surface in sandy soils, a drain must be made to carry off the water; it will also readily occur, that where a sandy soil rests upon a hard or clayey bottom, drains may likewise be necessary; but it is not unfrequently supposed, that where the subsoil is sand or gravel, thorough draining can seldom be required.

Every one, however, is familiar with the fact, that when water is applied to the bottom of a flower-pot full of soil, it will gradually find its way towards the surface, however light the soil may be. So it is in sandy soils or subsoils in the open field—all possess a certain power of sucking up water from beneath, (p. 131.) If water abound at the depth of a few feet, or if it so abound at certain seasons of the year, *that* water will rise towards the surface; and as the sun's heat dries it off by evaporation, more water will follow to supply its place. This attraction from beneath will always go on when the air is dry and

warm, and thus a double evil will ensue—the soil will be kept moist and cold, and instead of a constant circulation *of air downwards*, there will be a constant current *of water upwards*. Thus will the roots, the under soil, and the organic matter it contains, be all deprived of the benefits which the access of the air is fitted to confer, and both the crops and the farmer will suffer in consequence.* The remedy for these evils is to be found in an efficient system of drainage.

6°. It is a curious and apparently a paradoxical observation, that draining often improves soils on which the crops are liable to be *burned up* in seasons of drought. Yet, upon a little consideration, the fact becomes very intelligible. Let *a b* be the surface of the soil, and *c d* the level at which the water stagnates, or below which there is no outlet by drains or natural openings. The roots will readily penetrate to *c d*; but they will in general refuse to descend farther, because of the unwholesome substances which usually collect in water that is stagnant. Let a dry season come, and, their roots having little depth, the plants will be more or less speedily burnt up. And if water ascend from beneath the line *c d*, to moisten the upper soil, it will bring with it those noxious substances into which the roots have already refused to penetrate, and will cause the crop to droop and wither. But put in a drain, and lower the level of the water to *e f*, and the rains will wash out the noxious water from the subsoil, and the roots



* A few miles south of the town of Elgin in Morayshire, I was shown a tract of land on which the crops were usually three weeks later than on another tract, separated from it by a small stream. Beneath the former was a *pan* at the depth of 3 feet, which prevented the surface-water from sinking beyond that level, and thus retarded the growth of the crop.

will descend deep into it; so that if a drought again come, it may parch the soil above *c d*, as before, without injuring the plants, since now they are watered and fed by the soil beneath, into which the roots have descended.

7°. In many parts of the country, and especially in the red-sandstone districts, the oxide or rust of iron abounds so much in the soil, or in the springs which ascend into it, as gradually to collect in the subsoil, and form a more or less impervious layer or pan, into which the roots cannot penetrate, and through which the surface-water refuses to pass. Such soils are benefited, for a time, by breaking up the pan where the plough can reach it; but the pan gradually forms again at a greater depth, and the evils again recur. In such cases, the insertion of drains below the level of the pan is the most certain mode of permanently improving the soil. If the pan be now broken up, the rains sink through into the drains, and gradually wash out of the soil the iron which would otherwise have only sunk to a lower level, and have again formed itself into a solid cake.

8°. It is not less common, even in rich and fertile districts, to see crops of beans, or oats, or barley, come up strong and healthy, and shoot up even to the time of flowering, and then begin to droop and wither, till at last they more or less completely die away. So it is rare in many places to see a second year's clover crop come up strong and healthy. These facts indicate, in general, the presence of noxious matters in the subsoil, which are reached by the roots at an advanced stage of their growth, but into which they cannot penetrate without injury to the plant. The drain calls in the aid of the rains of heaven to wash away these noxious substances from the soil, and of the air to change their nature, and this is the

most likely, as well as the cheapest, means by which these evils can be prevented.

9°. Another evil in some countries presents itself to the practical farmer. Saline substances are in certain quantity beneficial, nay, even necessary to the growth of plants. In excess, however, they are injurious, and kill many valuable crops. I have already adverted to the existence of such saline substances in the soil, and to the fact of their rising in incrustations to the surface (p. 84) when droughts prevail.

In some countries, as in the plains of Athens, and near the city of Mexico, they come to the surface in such quantity as actually to kill the more tender herbage, and to permit only the stronger plants to grow. In the plains of Athens, when the rainy season ends, a rapid evaporation of water from the surface begins. The water, as it rises from beneath, brings much saline matter with it. This it leaves behind as it ascends in vapour, and thus at length so overloads the surface-soil that tender grass refuses to grow, though the stronger wheat plant thrives well and comes to maturity.

This result could scarcely happen if an outlet beneath were provided for the waters which fall during the rainy season. These would wash out and carry away the excess of saline matter which exists in the under soil, and would thus, when the dry weather comes, prevent it from ascending in such quantities as to injure the more tender herbage.

It may be objected to this suggestion, that drains in such countries would render more dry a soil already too much parched by the hot suns of summer. It is doubtful, however, if this would really be the case. Deep drains, as in the case above explained, (6°,) would enable the roots to

penetrate deeper, and would thus render them more independent of the moisture of the surface-soil.

10°. On this subject I shall add one important practical remark, which will readily suggest itself to the geologist who has studied the action of air and water on the various clay-beds that occur here and there, as members of the series of stratified rocks. *There are no clays which do not gradually soften under the united influence of air, of frost, and of running water. It is false economy, therefore, to lay down tiles of the common horse-shoe form without soles*, however hard and stiff the clay subsoil may appear to be. In the course of ten or fifteen years, the stiffest clays will *generally* soften so much as to allow the tile to sink to some extent—and many very much sooner. The passage for the water is thus gradually narrowed; and when the tile has sunk a couple of inches, the whole may have to be taken up. Thousands of miles of drains have been thus laid down, both in the low country of Scotland and in the southern counties of England, which have now become nearly useless. The extending use of the pipe-tile will, it is to be hoped, gradually lessen the chances of pecuniary loss, which the above practice involves.

SECTION III.—SUMMARY OF THE ECONOMICAL ADVANTAGES OF DRAINING.

The *economical* advantages of draining in such soils as we possess are chiefly these:—

1. Stiff soils are more easily and more cheaply worked.
2. Lime and manures have more effect, and go farther.
3. Seed-time and harvest are earlier and more sure.
4. Larger crops are reaped, and of better quality.
5. Valuable crops of wheat and turnips are made to

grow where scanty crops of oats were formerly the chief return.

6. Naked fallows are rendered less necessary, and more profitable rotations can be introduced.

7. The climate is improved, and rendered not only more suited to the growth of crops, but more favourable to the health of man and other animals.

SECTION IV.—OF THE DEPTH TO WHICH DRAINS OUGHT TO BE DUG.

Much has lately been written in regard to the depth to which drains ought to be dug in a system of thorough drainage. It is difficult, perhaps impossible, to establish any empirical or general rule upon this subject; but there are certain indisputable points which will serve to guide the intelligent farmer in most cases which are likely to occur.

1°. It is acknowledged, as a general rule, to be of great importance that the soil should be deepened—that it should be opened up, for the descent of the roots, to the greatest depth to which it can be economically done. Now, by the use of the subsoil-plough or the fork, the soil can be stirred to a depth of from 22 to 24 inches. The tile —or the top of the drain, if made of stones—should be at least three inches clear of this disturbance of the upper soil; and as most tiles will occupy at least 3 inches, we reach 30 inches as the minimum depth of a tile drain, and about 3 feet as the minimum depth of a stone drain, in which the layer of stones has a depth of not more than 9 inches.

2°. Where the outfall is bad, and a depth of 30 or 36 inches cannot be obtained, the drains should be made as deep as they can be made to run and deliver water.

3°. The roots of our corn and other crops will, in favourable circumstances, descend to a depth of 4 or 5 feet. They do so in quest of food, and the crop above ground is usually the more luxuriant the deeper the roots are enabled to penetrate. It is, therefore, theoretically desirable to dry the soil to a greater depth even than 3 feet, where it can be done without too great an outlay of money.

4°. The question of economy, therefore, is one of great importance in this inquiry. In some places it costs as much to dig out the fourth or lowest foot as is paid for the upper three; and this additional cost is, in many localities, a valid reason for limiting the depth to 30 inches, or 3 feet.

5°. But the question of economy ought to be disregarded, and deeper drains dug where springs occur beneath, or where, by going a foot deeper, a bed or layer is reached in which much water is present. The reason of this is—that though water may not rise from this wet layer in such quantity as actually to run along the drains, yet it may do so in sufficient abundance to keep the subsoil moist and cold, and thus to retard the development of the crops that grow on its surface.

The above circumstances appear sufficient to guide the practical man in most cases that will present themselves to him. No uniform depth can be fixed upon; it must be modified by local circumstances.

In regard to the distance apart at which drains should be placed, experience appears to be the only satisfactory guide. This says, as yet, that 18 to 21 feet are safe distances, and that drains placed at greater distances are doubtful, and may fail to dry the land.

SECTION V.—EFFECTS PRODUCED BY THE RAINS AS THEY DESCEND THROUGH THE SOIL.

The most important immediate effect of thorough-drainage is, that it enables the rain or other surface water to descend more deeply and escape more rapidly from the soil. It may be interesting to specify briefly the benefits which are known to follow from this descent of the rain through the soil.

1°. *It causes the air to be renewed.*—It is believed that the admission of frequently renewed supplies of air into the soil is favourable to its fertility. This the descent of the rain promotes. When it falls upon the soil it makes its way into the pores and fissures, expelling of course the air which previously filled them. When the rain ceases, the water runs off by the drains; and as it leaves the pores of the soil empty above it, the air follows, and fills with a renewed supply the numerous cavities from which the descent of the rain had driven it. Where land remains full of water, no such renewal of air can take place.

2°. *It warms the under soil.*—As the rain falls through the air it acquires the temperature of the atmosphere. If this be higher than that of the surface soil, the latter is warmed by it; and if the rains be copious, and sink easily into the subsoil, they will carry this warmth with them to the depth of the drains. Thus the under soil in well drained land is not only warmer, because the evaporation is less, but because the rains in the summer season actually bring down warmth from the heavens to add to their natural heat.

3°. *It equalises the temperature of the soil during the season of growth.*—The sun beats upon the surface of the soil,

and gradually warms it. Yet, even in summer, this direct heat descends only a few inches beneath the surface. But when rain falls upon the warm surface, and finds an easy descent, as it does in open soils, it becomes itself warmer, and carries its heat down to the under soil. Then the roots of plants are warmed, and general growth is stimulated.

It has been proved, by experiments with the thermometer, that the under as well as the upper soil is warmer in drained than in undrained land, and the above are some of the ways by which heat seems to be actually added to soils that have been thoroughly drained.

4°. *It carries down soluble substances to the roots of plants.*—When rain falls upon heavy undrained land, or upon any land into which it does not readily sink, it runs over the surface, dissolves any soluble matter it may meet with, and carries it into the nearest ditch or brook. Rain thus robs and impoverishes such land.

But let it sink where it falls—then whatever it dissolves it will carry downwards to the roots—it will distribute uniformly the saline matters which have a natural tendency to rise to the surface, and it will thus promote growth by bringing food everywhere within the reach of plants.

5°. *It washes noxious matters from the under soil.*—In the subsoil, beyond the reach of the air, substances are apt to collect, especially in red-coloured soils, which are injurious to the roots of plants. These the descent of the rains alters in part and makes wholesome, and in part washes out. The plough may then safely be trusted deeper, and the roots of plants may descend in search of food where they would previously have been destroyed.

It is true that, when heavy rains fall, they will also wash out of the soil and carry into the drains substances which it would be useful to retain. Upon this fact some

have laid unnecessary stress, and have adduced it as an argument against thorough-drainage. But if we balance the constant benefit against the occasional evil, I am satisfied, as experience indeed has shown, that the former will greatly preponderate.

6°. *It brings down fertilising substances from the air.*—Besides, the rains never descend empty-handed. They constantly bear with them gifts, not only of moisture to the parched herbage, but of organic and saline food, by which its growth is promoted. Ammonia and nitric acid, (p. 34,) together with the many exhalations which are daily rising from the earth's surface, come down in the rains; common salt, gypsum, and other saline substances derived from the sea, are rarely wanting; and thus, the constant descent from the heavens may well be supposed to counterbalance the occasional washings from the earth.

7°. *Much of the rain is evaporated.*—And lastly, in answer to this objection, it is of importance to state, that in our climate a very large proportion of the rain that falls does not sink through the soil, even where there are drains beneath, but rises again into the air in the form of watery vapour. Experiments in Manchester have shown, that of 31 inches of rain which fall there in a year, 24 are evaporated; while in Yorkshire, of 24½ inches of rain which fall, only 5 inches run off through pipes laid at a depth of 2 feet 9 inches, the rest being evaporated. There is little cause, therefore, for the fear expressed by some, that the draining of the land will cause the fertility in any perceptible degree to diminish in consequence of the washing of the descending rains. They may, as I have said, improve the subsoil by washing hurtful substances out of it; but, in general, the soil will have extracted from the water which filters through it all the valuable matter it holds in solution before it has reached the depth of a 3-feet drain.

CHAPTER XI.

Mechanical methods continued.—The subsoil-plough and the fork.—How they act in improving the soil.—Experiments on the profit of subsoiling.—How deep ploughing and trenching improve the soil.—Chemical and other effects of common ploughing.—Improvement of the soil by mixing.

After the land has been laid dry by drains, other mechanical modes of improvement can be employed with advantage. Even the ordinary methods of mechanical culture become more useful, and the benefits which in favourable circumstances are derived from turning up the soil are greater and more manifest. These facts will appear by a brief consideration of the effects produced by ploughing to various depths, and the causes from which they arise.

SECTION I.—USE OF THE SUBSOIL-PLOUGH. HOW IT ACTS IN IMPROVING THE SOIL.

The subsoil-plough is an auxiliary to the drain—it stirs and opens the under soil without mixing it with the upper or immediately active soil. Though there are few subsoils through which the water will not at length make its way, yet there are some so stiff, either naturally or from long consolidation, that the good effect of a well-arranged line of drains is lessened by the slowness with which they allow the superfluous water to pass through

them. In such cases, the use of the subsoil-plough is most advantageous in loosening the under layers of soil, and in allowing the water to find a ready escape downwards to either side, until it reaches the drains.*

It is well known that if a piece of stiff clay be cut into the shape of a brick, and then allowed to dry, it will contract and harden—it will form an air-dried brick, almost impervious to any kind of air. Wet it again, it will swell and become still more impervious. Cut up *while wet*, it will only be divided into so many pieces, each of which will harden when dry, or the whole of which will again attach themselves and stick together if exposed to pressure while they are still wet. But tear it asunder *when dry*, and it will fall into many pieces, will more or less crumble, and will readily admit the air into its inner parts. So it is with a clay subsoil.

After the land is provided with drains, the subsoil being very retentive, the subsoil-plough is used to open it up—to let out the water and let in the air. If this is not done, the stiff under clay will contract and bake as it dries, but it will neither sufficiently admit the air, nor open so free a passage for the roots. Let this operation, however, be performed when the clay is still too wet, a good effect will follow in the first instance; but after a while the cut clay will again cohere, and the farmer will pronounce subsoiling to be a useless expense *on his land*. Defer the use of the subsoil-plough till the clay is dry—it will then *tear* and *break* instead of *cutting* it, and its openness will remain. Once give the air free access, and, after a time, it so modifies the drained clay that it no longer has an equal tendency to cohere.

Mr Smith of Deanston very judiciously recommended

* For a fuller discussion of the benefits of drainage, see the Author's *Lectures*, 2d edition, p. 550.

that the subsoil-plough should never be used till at least a year after the land has been thoroughly drained. This in many cases will be a sufficient safeguard—will allow a sufficient time for the clay to dry: in other cases, two years may not be too much. But this precaution has by some been neglected; and, subsoiling being with them a failure, they have sought, in some supposed chemical or other quality *of their soil*, for the cause of a want of success which is to be found in their own neglect of a most necessary precaution. Let not the practical man be too *hasty* in desiring to attain those benefits which attend the adoption of improved modes of culture; let him give every method a fair trial; *and above all, let him make his trial in the way and with the precautions recommended by the author of the method*, before he pronounce its condemnation.

SECTION II.—EXPERIMENTS ON THE PROFIT OF SUBSOILING. USE OF THE FORK.

The benefits of subsoil ploughing having been sometimes called in question, and there being even some cases on record in which positive injury has been said to follow from the practice, I introduce the following numerical results observed on two farms in the neighbourhood of Penicuik, a few miles from Edinburgh.

1°. Mr Wilson of Eastfield, Penicuik, made an experiment, after thorough drainage, upon two portions of land under each of three crops, and found the effects in the first year after subsoil ploughing, compared with ordinary ploughing, to be as follows:—

	Turnips.	Barley.		Potatoes
		Grain.	Straw.	
	tons. cwt.	qrs.	cwt.	tons. cwt.
Ploughed to 8 inches, . .	20 7	7½	28	6 14¼
Subsoiled to 15 inches, .	26 17	8⅜	36½	7 9½
Difference, .	6 10	⅞	8½	15¼

From this table, the effects of subsoiling to a depth of 15, above that of ploughing to a depth of 8 inches, appears to have been to increase the turnip crop by 6½ tons, the potatoes by 15 cwt., and the barley by 7 bushels of grain and 8 cwt. of straw.

2°. Mr Maclean of Braidwood, near Penicuik, made a similar experiment with turnips and barley, with the following results:—

	Turnips.	Barley.	
		Grain.	Straw.
	tons. cwt.	qrs.	stones.
Ploughed 8 inches deep, . .	19 15	6¾	168½
Subsoiled to 15 inches, . .	23 17	7¾	206½
Difference, . .	4 2	1	38

The turnip crop, in this experiment, was increased 4 tons; and the barley crop by 6 bushels of grain and 38 stones of straw.

It has been observed, also, that the effects of the subsoiling do not cease with the first crop. In one case, in which an accurate account of the produce was kept, the profit was estimated at 6s. an acre, *for five successive years after the operation.* There is reason, therefore, to anticipate general good from the careful introduction of this practice; though it is exceedingly desirable, at the same

that the subsoil-plough should never be used till at least a year after the land has been thoroughly drained. This in many cases will be a sufficient safeguard—will allow a sufficient time for the clay to dry: in other cases, two years may not be too much. But this precaution has by some been neglected; and, subsoiling being with them a failure, they have sought, in some supposed chemical or other quality *of their soil*, for the cause of a want of success which is to be found in their own neglect of a most necessary precaution. Let not the practical man be too *hasty* in desiring to attain those benefits which attend the adoption of improved modes of culture; let him give every method a fair trial; *and above all, let him make his trial in the way and with the precautions recommended by the author of the method*, before he pronounce its condemnation.

SECTION II.—EXPERIMENTS ON THE PROFIT OF SUBSOILING. USE OF THE FORK.

The benefits of subsoil plo[illegible]ng having [illegible] times called in question, an[illegible]ing [illegible] on record in which positi[illegible] from the practice, I [illegible] results observed on [illegible] Penicuik, a few m[illegible]

1°. Mr Wils[illegible] ment, after [illegible] under ea[illegible] first y[illegible] plo[illegible]

	Turnips.		Barley. Grain.	Barley. Straw.	Potatoes.	
	tons.	cwt.	bush.	cwt.	tons.	cwt.
Ploughed to 8 inches . . .	[illegible]	—	[illegible]	[illegible]	[illegible]	[illegible]
Subsoiled to 15 inches . . .	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]
Difference . . .	[illegible]	[illegible]	[illegible]	8		[illegible]

From this table, the effects of subsoiling to a depth of 15, above that of ploughing to a depth of 8 inches, appears to have been to increase the turnip crop by [illegible] tons, the potatoes by 15 cwt., and the barley by 7 bushels of grain and 8 cwt. of straw.

2. Mr Maclean of Braidwood, near Penicuik, made a similar experiment with turnips and barley with the following results:—

	Turnips.		Barley. Grain.	Barley. Straw.
	tons.	cwt.	bus.	stones.
Ploughed 8 inches deep . . .	19	15	[illegible]	[illegible]
Subsoiled to 16 inches . . .	23	17	[illegible]	[illegible]
Difference . . .	4	2	[illegible]	[illegible]

The [illegible] experiment [illegible] increased [illegible] by [illegible] grain and [illegible]

It has [illegible] the sub-[illegible] the [illegible] case, in [illegible] of [illegible] kept, the [illegible] is an [illegible] genera[illegible] There [illegible], to suffici-[illegible] duction of this [illegible] a c[illegible], at the same

time, that the causes of its failure, wherever it is found to fail, should be rigorously investigated.

The use of the fork, instead of the subsoil-plough, has lately been recommended as a more efficient, and even a more economical method of opening up the under soil. The upper soil of 9 to 12 inches is thrown forward with a spade, and the under soil, to a depth of 15 inches further, is stirred and turned over with a three-pronged fork. I have seen it in operation; and it certainly does appear to loosen and open up the under soil more effectually than the subsoil-plough can do, and to a depth which few subsoil-ploughs are yet able to reach.

SECTION III.—HOW DEEP PLOUGHING AND TRENCHING IMPROVE THE SOIL.

1°. *Deep ploughing*, like subsoiling, aids the effect of the drains, and so far—where it goes nearly as deep—even more completely effects the same object. But, independently of this, it has other uses and merits, and, where it has been successfully applied, has improved the land by the operation of other causes.

Subsoiling only lets out the water, and allows access to the air and rains, and a free passage to the roots. Deep ploughing, in addition to these, brings new earth to the surface, forms thus a deeper active soil, and more or less alters both its physical qualities and its chemical composition.

If the plough be made to bring up 2 inches of clay or sand, it will stiffen or loosen the soil, as the case may be; or it may affect its colour or density. It is clear and simple enough, therefore, that, by deep ploughing, the physical properties of the soil may be altered.

But there are certain substances contained in every soil, whether in pasture or under the plough, which gradually

make their way down towards the subsoil. They sink till they reach at last that point beyond which the plough does not usually penetrate. Every farmer knows that lime thus sinks. In peaty soils top-dressed with clay, as is done in Lincolnshire, the clay thus sinks. In sandy soils, also, which have been clayed, the clay sinks: and in all these cases, I believe, the sinking takes place more rapidly when the land is laid down to grass. Where soils are marled, the marl sinks; and the rains, in like manner, gradually wash out that which gives their fertilising virtue to the large doses of chalk which in some districts are spread upon the land, and render necessary a new application to renovate its productive powers.

If this be the case with earthy substances such as those now mentioned, which are, for the most part, insoluble in water, it will be readily believed that those saline ingredients of the soil which are easily soluble, will be still sooner washed out of the upper and conveyed to the under soil. Thus the subsoil may gradually become rich in those substances of which the surface soil has been robbed by the rains. Bring up a portion of this subsoil by deep-ploughing, and you restore to the surface soil a part of what it has been gradually losing—you bring up what may probably render it more fruitful than before. Such is an outline of the reasons in favour of deep ploughing.

In Germany, theory has pointed out the growing of an occasional *deep-rooted* crop in light soils to effect the same end. The deep roots bring up again to the surface the substances which had naturally sunk.

But suppose the land to have originally contained something noxious to vegetation, which in process of time has been washed down into the subsoil, then to bring this again to the surface would be materially to injure the land. This also is true, and a sound discretion must be

employed, in judging when and where such evil effects are likely to follow.

Such cases, however, are more rare than many suppose. There are few subsoils which, *after a year's draining*, a full and fair exposure to the winter's frost will not in a great degree deprive of all their noxious qualities, and render fit to ameliorate the general surface of the poorer lands. If the reader doubt this fact, let him visit Yester, and give a calm consideration to the effects produced by deep ploughing on the home farm of the Marquis of Tweeddale. Let him also study the practice of deep ploughing as it is followed by the Jersey farmers, and he will be still further persuaded of the value of deep-ploughing, in some localities at least.

In many cases the farmer fears, as he does in some parts of the county of Durham, to bring up a single inch of the yellow clay that lies beneath his surface soil. In the first inch lodges, among other substances, the iron worn from his plough, which, in some soils, and after a lapse of years, amounts to a considerable quantity. Till it is exposed to the air, this iron is hurtful to vegetation; and one of the benefits of a winter's exposure of such subsoils to the air arises from the effect produced upon the iron they contain.

It is the want of drainage, however, and of the free access of air, that most frequently renders subsoils for a time injurious to vegetation. Let the lands be well drained—let the subsoils be washed for a few years by the rain water passing through them—and there are few of those which are clayey in their nature that may not ultimately be brought to the surface, not only with safety, but with advantage to the upper soil.

2°. *Trenching* with the spade more fully and effectually performs what the trench-plough is intended to do. The spade more completely turns over the soil than the plough

does; and, in the hands of an industrious labourer, many think it the more economical instrument of the two.

SECTION IV.—CHEMICAL AND OTHER EFFECTS OF COMMON PLOUGHING.

Other benefits, again, attend upon the ordinary ploughings, hoeings, and working of the land. Its parts are more minutely divided—the air gets access to every particle—it is rendered lighter, more open, and more permeable to the roots. The vegetable matter it contains decomposes more rapidly by a constant turning of the soil, so that wherever the fibres of the roots penetrate, they find organic food provided for them, and an abundant supply of the oxygen of the atmosphere to aid in preparing it. The production of ammonia and of nitric acid also, (see pages 27 to 33,) and the absorption of these and of watery vapour from the air, take place to a greater extent the finer the soil is pulverised, and the more it has been exposed to the action of the atmosphere. All soils contain, likewise, an admixture of fragments of those minerals of which the granitic and trap rocks are composed, which, by their decay, yield new supplies of inorganic food to the growing plant. The more frequently they are exposed to the air, the more rapidly do these fragments crumble away and decompose. The general advantage, indeed, to be derived from the constant working of the soil, may be inferred from the fact, that Tull reaped twelve successive crops of wheat from the same land by the repeated use of the plough and the horse-hoe. There are few soils so stubborn as not to show themselves grateful in proportion to the amount of this kind of labour that may be bestowed upon them.

It is chiefly because the spade or the fork divides and

separates the soil more completely, or to a greater depth, that larger crops have been obtained in many districts by the introduction of spade husbandry than by the ordinary mode of culture with the plough. But all these benefits, which a thorough working of the soil is fitted to confer, are only fully realised where the land is naturally dry, or by artificial drainage has been freed from superfluous water.

SECTION V.—OF THE IMPROVEMENT OF THE SOIL BY MIXING.

It has been already shown that the physical properties of the soil have an important influence upon its average fertility. The admixture of pure sand with clay soils produces an alteration which is often beneficial, and which is almost wholly physical. The sand opens the pores of the clay, and makes it more permeable to the air.

The admixture of clay with sandy or peaty soils, however, produces both a physical and a chemical alteration. The clay not only consolidates and gives body to the sand or peat, but it also mixes with them certain earthy and saline substances, useful or necessary to the plant, which neither the sand nor peat might originally contain in sufficient abundance. It thus alters its chemical composition, and fits it for nourishing new races of plants.

Such is the case also with admixtures of marl, of shell-sand, and of lime. They slightly consolidate the sands and open the clays, and thus improve the mechanical texture of both kinds of soil; but their main operation is chemical; and the almost universal benefit they produce depends mainly upon the new chemical element they introduce into the soil.

It is a matter of almost universal remark, that in our climate, soils are fertile—clayey or loamy soils, that is—

only when they contain an appreciable quantity of lime. In whatever way it acts, therefore, the mixing of lime in any of the forms above mentioned, with a soil in which little or no lime exists, is one of the surest practical methods of bringing it nearer in composition to those soils from which the largest returns of agricultural produce are usually obtained. Some of the chemical effects of lime upon the soil will be explained in a subsequent chapter.

CHAPTER XII.

Improvement of the soil by planting and the growth of wood.—Influence of the Scotch fir and the larch on the value of pasture.—Causes of such influence of growing trees.—Improvement by laying down to grass.—Observed facts.—Forms which the improvement assumes.—In what way pastures generally increase in value by age.—Agency of roots, of insects, and of winds.—Why rich pasture, when ploughed up, is difficult to restore.

THERE are certain modes of improving the soil, which, though involving only simple mechanical operations on the part of the improver, produce their effects through the agency of refined scientific causes. Such are the improvements produced by planting and laying down to grass. These, therefore, I shall briefly consider in the present chapter.

SECTION I.—IMPROVEMENT OF THE SOIL BY PLANTING, AND HOW IT IS EFFECTED.

It has been observed that lands which are unfit for arable culture, and which yield only a trifling rent as natural pasture, are yet in many cases capable of growing profitable plantations, and of being greatly increased in permanent value by the prolonged growth of wood. Not only, however, do all trees not thrive alike on the same soil, but all do not improve the soil on which they grow in an equal degree.

Under the Scotch fir, for example, the pasture which

springs up after a lapse of years is not worth 6d. more per acre than before the land was planted;—under the beech and spruce, it is worth even less than before, though the spruce affords excellent shelter;—under the ash, it gradually acquires an increased value of 2s. or 3s. per acre. In oak copses, it becomes worth 5s. or 6s., but only during the last eight years (of the twenty-four) before the oak copse is cut down. But under the larch, after the first thirty years, when the thinnings are all cut, land not worth originally more than 1s. per acre becomes worth 8s. to 10s. per acre for permanent pasture.*

1. The main cause of this improvement is to be found in the nature of the soil, which gradually accumulates beneath the trees by the shedding of their leaves. The shelter from the sun and rain which the foliage affords, prevents the vegetable matter which falls from being so speedily decomposed, or from being so much washed away, and thus permits it to collect in larger quantities in a given time than where no such cover exists. The more complete the shelter, therefore, the more rapid will the accumulation of soil be, in so far as it depends upon this cause.

2. But the quantity of leaves which annually fall, as well as the degree of rapidity with which, under ordinary circumstances, they undergo decay, have also much influence upon the extent to which the soil is capable of being improved by any given species of tree. The broad leaves of the beech and oak decay more quickly than the needle-shaped leaves of the pine tribes, and this circumstance may assist in rendering the larch more valuable as a permanent improver.

3. We should expect, likewise, that the quantity and

* The result of trials made on the *mica slate* and *gneiss* soils (see page 112) of the Duke of Atholl.

quality of the inorganic matter contained in the leaves (p. 65)—brought up year by year from the roots, and strewed afterwards uniformly over the surface where the leaves are shed—would materially affect the value of the soil they form. The dry leaves of the oak, for example, contain about 5 per cent of saline and earthy matter, while those of the Scotch fir contain less than 2 per cent; so that, supposing the actual weight of leaves which falls from each kind of tree to be equal, we should expect a greater depth of soil to be formed in the same time by the oak than by the Scotch fir. The leaves of the larch in the dry state contain from 5 to 6 per cent of saline matter, so that they may enrich the surface on which they fall in at least an equal degree with those of the oak. Much, however, depends upon the annual weight of leaves shed by each kind of tree, in regard to which we possess no precise information.

The improvement of the land, therefore, by the planting of trees, depends in part upon the quantity of *organic* food which the trees can extract from the air, and afterwards drop in the form of leaves upon the soil, and in part upon the kind and quantity of *inorganic* matter which the roots can bring up from beneath, and in like manner strew upon the surface. The quantity and quality of the latter will, in a great measure, determine the kind of grasses which will spring up, and the consequent value of the pasture in the feeding of stock. In the larch forests of the Duke of Atholl, the most abundant grasses that spring up are said to be the Holcus mollis, and the Holcus lanatus (the *creeping* and the *meadow* soft grasses.)

The action of a tree, therefore, in improving the soil, is twofold.

1°. It causes vegetable matter to accumulate on the surface; and,

2°. It brings up from beneath certain substances which are of vital importance to the growth of plants, but of which the upper soil may have been deficient.

In a previous chapter I have described the *black earth* of Central Russia, which presents probably the most remarkable example now existing of the fertilising effect of a long-continued growth of trees. The cotton soil of Central and Southern Hindostan owes its richness to a similar cause.

SECTION II.—IMPROVEMENT OF THE SOIL BY LAYING DOWN TO GRASS. FACTS WHICH HAVE BEEN ASCERTAINED.

On this subject, two facts seem to be pretty generally acknowledged.

First, That land laid down to artificial grasses for one, two, three, or more years, is in some degree rested or recruited, and is fitted for the better production of after crops of corn. Letting it lie a year or two longer in grass, therefore, is one of the received modes of bringing back to a sound condition a soil that has been exhausted by injudicious cropping.

Second, That land thus laid down with artificial grasses diminishes in value again after two, three, or five years—more or less—and only by slow degrees acquires a thick sward of rich, nourishing natural herbage. Hence the opinion that grass land improves in quality the longer it is permitted to lie—the unwillingness to plough up old pasture—and the comparatively high rents which, in some parts of the country, old grass land is known to yield.

Granting that grass land does thus *generally* increase in value, three important facts must be borne in mind before we attempt to assign the cause of this improvement, or

the circumstances under which it is likely to take place for the longest time and to the greatest extent.

1. The value of the grass in any given spot may increase for an indefinite period, but it will never improve beyond a certain extent—it will necessarily be limited, as all other crops are, by the quality of the land. Hence the mere laying down to grass will not make *all* land *good*, however long it may lie. The extensive commons, heaths, and wastes, which have been in grass from the most remote times, are evidence of this. They have, in most cases, yielded so poor a natural herbage as to have been considered unworthy of being enclosed as permanent pasture.

2. Some grass-lands will retain the good condition they thus slowly acquire for a very long period, and *without manuring*—in the same way, and upon nearly the same principle, that some rich corn-lands have yielded successive crops for 100 years without manure. The rich grass-lands of England, and especially of Ireland, many of which have been in pasture from time immemorial, without receiving any known return for all they have yielded, are illustrations of this fact.

3. But others, if grazed, cropped with sheep, or cut for hay, will gradually deteriorate, unless some proper supply of manure be given to them—which required supply must vary with the nature of the soil, with the kind of stock fed upon it, and with the kind of treatment to which it has been subjected.

SECTION III.—FORM WHICH THE IMPROVEMENT ASSUMES, AND HOW IT IS BROUGHT ABOUT.

In regard to the acknowledged benefit of laying down to grass, then, two points require consideration.

1°. What form does it assume—and how is it effected?

The improvement takes place by the gradual accumulation of a dark-brown soil rich in vegetable matter, which soil thickens or deepens in proportion to the time during which it is allowed to lie in grass. It is a law of nature, that this accumulation takes place more rapidly in the temperate than in tropical climates, and it would appear as if the consequent darkening of the soil were intended, among other purposes, to enable it to absorb more of the sun's warmth, and thus more speedily to bring forward vegetation where the average temperature is low and the summers comparatively short.

If the soil be very light and sandy, the thickening of the vegetable matter is sooner arrested; if it be moderately heavy land, the improvement continues for a longer period; and some of the heaviest clays in England are known to bear the richest permanent pastures.

The soils formed on the surface of all our rich old pasture lands thus come to possess a remarkable degree of uniformity—both in physical character and in chemical composition. This uniformity they gradually *acquire*, even upon the stiff clays of the lias and Oxford clay, which originally, no doubt, have been left to natural pasture—as many clay lands still are—from the difficulty and expense of submitting them to arable culture.

2°. How do they acquire this new character, and why is it the work of so much time?

a. When the young grass throws up its leaves into the air, from which it derives so much of its nourishment, it throws down its roots into the soil in quest of food of another kind. The leaves may be mown or cropped by animals, and carried off the field; but the roots remain in the soil, and, as they die, gradually fill its upper part with vegetable matter. On an average, the *annual* production

of roots on old grass-land is equal to one-third or one-fourth of the weight of hay carried off*—though no doubt it varies much, both with the kind of grass and with the kind of soil. When wheat is cut down, the quantity of straw left in the field, in the form of stubble and roots, is sometimes greater than the quantity carried off in the sheaf. Upon a grass field two or three tons of hay may be reaped from an acre, and therefore, from half a ton to a ton of dry roots is annually produced and left in the soil. If anything like this weight of roots die every year, in land kept in pasture, we can readily understand how the vegetable matter in the soil should gradually accumulate. In arable land this accumulation is prevented by the constant turning up of the soil, by which the fibrous roots, being exposed to the free access of air and moisture, are made to undergo a more rapid decomposition.

b. But the roots and leaves of the grasses contain earthy and saline matters also. Dry hay leaves from an eighth to a tenth part of its weight of ash when burned. Along with the dead vegetable matter of the soil, this inorganic matter also accumulates in the form of an exceedingly fine earthy powder; hence one cause of the universal fineness of the surface-mould of old grass-fields. The earthy portion of this inorganic matter consists chiefly of silica, lime, and magnesia, with scarcely a trace of alumina; so that, even on the stiffest clays, a surface soil may be ultimately formed, in which the quantity of alumina—the substance of clay—is comparatively small.

c. There are still other agencies at work, by which the surface of stiff soils is made to undergo a change. As the roots of the grasses penetrate into the clay, they more or

* See the Author's *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 745.

less open up a way into it for the rains. Now, the rains in nearly all lands, when they have a passage downwards, have a tendency to carry down the clay along with them. They do so, it has been observed, on sandy and peaty soils, and more quickly when these soils are laid down to grass. Hence the mechanical action of the rains—slowly in many localities, yet surely—has a tendency to lighten the surface soil, by removing a portion of its clay. They constitute one of those natural agencies by which, as elsewhere explained, important differences are ultimately established, almost everywhere, between the surface crop-bearing soil and the subsoil on which it rests.

d. But further, the heats of summer and the frosts of winter aid this slow alteration. In the extremes of heat and of cold, the soil contracts more than the roots of the grasses do; and similar, though less visible, differences take place during the striking changes of temperature which are experienced in our climate in the different parts of almost every day. When the rain falls, also, on the parched field, or when a thaw comes on in winter, the earth expands, while the roots of the grasses remain nearly fixed; hence the soil rises up among the leaves, mixes with the vegetable matter, and thus assists in the slow accumulation of a rich vegetable mould.

The reader may have witnessed in winter how, on a field or by a way-side, the earth rises above the stones, and appears inclined to cover them; he may even have seen, in a deserted and undisturbed highway, the stones gradually sinking and disappearing altogether, when the repetition of this alternate contraction and expansion of the soil for a succession of winters has increased, in a great degree, the effects which follow from a single accession of frosty weather.

So it is in the fields. And if a person skilled in the

soils of a given district can make a guess at the time when a given field was laid down to grass, by the depth at which the stones are found beneath the surface, it is partly because this loosening and expansion of the soil, while the stones remain fixed, tends to throw the latter down by an almost imperceptible quantity every year that passes.

e. Such movements as these act in opening up the surface soil, in mixing it with the decaying vegetable matter, and in allowing the slow action of the rains gradually to give its earthy portion a lighter character. But with these, among other causes, conspires also the action of living animals. Few persons have followed the plough without occasionally observing the vast quantities of earth-worms with which some fields seem to be filled. On a close-shaven lawn, many have noticed the frequent little heaps of earth which these worms during the night have thrown out upon the grass. These and other minute animals are continually at work, especially beneath an undisturbed and grassy sward—and they nightly bring up from a considerable depth, and discharge on the surface, their burden of fine fertilising loam [illegible] Each of these burdens is an act[illegible] gai[illegible] and who can [illegible] and unar[illegible] both [illegible] d[illegible]

f. In most localities, also, the winds may be mentioned among the natural agencies by which the soil on grass lands is slowly improved. They seldom sweep over any considerable extent of arable land without bearing with them particles of dust and sand, which they drop in sheltered places, or leave behind them when sifted by the blades of grass, or by the leaves of an extensive forest. In hot summers, in dry springs, and even in winter, when the snow is drifting, the ploughed lands and dusty roads are more or less bared of their lighter particles of soil, which are strewed by the winds as a natural top-dressing over the neighbouring untilled fields.

In some countries the agency of the winds is more conspicuous than among ourselves. Thus on the banks of the Kuruman and Orange rivers in South Africa, the winds blow during the spring months — August to November in that climate — from the Kulagare desert, bearing with them light particles of dust, which make the air seem as if dense with smoke, and which are so exquisitely fine as to penetrate through seams and cracks which are almost impervious to water.* Forest trees and waving grass sift this thick air and enrich the soils on which they grow by the earthy particles they arrest.

In countries where active volcanoes exist, these also exercise an appreciable influence of a similar kind upon the surface soil. Showers of dust and ashes are sprinkled widely over the land, by which its natural agricultural capabilities are materially interfered with. Vesuvius is said, in this way, to scatter its ashes over the adjoining country, so as, on an average, to destroy the crop every eighth year. But to this circumstance the remarkable general richness of the soil is ascribed—(MOHL.) So does good arise from seeming evil.

* *Moffat's Missionary Labours*, p. 333.

There are natural causes, then, which we *know* to be at work, that are sufficient to account for nearly all the facts that have been observed in regard to the effect of laying land down to grass. Stiff clays will gradually become lighter on the surface, and, if the subsoil be rich in all the kinds of inorganic food which the grasses require, will go on improving for an indefinite period without the aid of manure. Let them, however, be deficient in, or let them gradually become exhausted of any one kind of this food, and the grass lands will either gradually deteriorate after they have reached a certain degree of excellence, or they must be supplied with that one ingredient, that one kind of manure of which they stand in need. It is doubtful if any pasture lands are so naturally rich as to bear to be cropped for centuries without the addition of manure, and at the same time without deterioration. Where they appear to be so, they probably receive from springs, from sea-drift, or from some other unobserved source, those perennial supplies which reason pronounces to be indispensable.

On soils that are light, again—which naturally contain little clay — the grasses will thrive more rapidly, and a thick sward will be sooner formed, but the tendency of the rains to wash out the clay may prevent them from ever attaining that luxuriance which is observed upon the old pastures of the clay lands.

On undrained heaths and commons, and generally on any soil which is deficient in some fertilising element, neither abundant herbage, nor good crops of any other kind, can be expected to flourish. Laying such lands down, or permitting them to remain in grass, may prepare them for by-and-by yielding one or two average crops of corn, but cannot be expected *alone* to convert them into valuable pasture.

Finally, plough up the old pastures on the surface of which this light and most favourable soil has been long accumulating, and the heavy soil from beneath will be again mixed up with it, the vegetable matter will disappear rapidly by exposure to the air during the frequent ploughings; and, if again laid down to grass, the slow changes of many years must again be begun through the agency of the same natural causes, before it become capable a second time of bearing the same rich herbage it was known to nourish while it lay undisturbed.

Many have supposed that, by sowing down with the *natural* grasses, a thick and permanent sward may at once be obtained; and on light loamy land, rich in vegetable matters, this method may, to a certain extent, succeed; but, on heavy land, in which stiff clay abounds and vegetable matter is defective, disappointment will often follow the sowing of the most carefully selected seeds. By the agency, among other causes, of those above adverted to, *the soil gradually changes*, so that it is unfit, when first laid down, to bear those grasses which, ten or twenty years afterwards, will spontaneously and luxuriantly grow upon it. Nature is not regulated by one principle in the growth of corn and by another in growing grass; the apparent difference in her procedure arises from real differences in our practice.

CHAPTER XIII.

Chemical methods of improving the soil.—Use of manures.—Objects of the farmer.—Vegetable manures.—Green manuring.—Use of sea-weed. — Dry vegetable substances. — Straw. — Sawdust.— Bran.— Brewers' grains.—Malt-dust.—Rape-dust.—Hemp, poppy, cotton, and cocoa-nut cakes.—Use of peat.—Peat composts and tanners' bark.—Use of vegetable substances decomposed by art.—Charred peat, wood charcoal, soot, coal-dust, and coal-tar.—Relative fertilising and money values of different vegetable manures.

NONE of the methods of improving the soil which have been described in the preceding chapter are purely mechanical. They all involve, as I have shown, some chemical alterations also, which are to be explained only by a knowledge of chemical principles. But the manuring of the land is more strictly a chemical operation, and may therefore with propriety be separated from those methods of improvement which involve at the same time important and expensive mechanical operations.

In commencing the tillage of a piece of land, the conscientious farmer may have three objects in view in regard to it.

1. He may wish to reclaim a waste, or to restore a neglected farm to an average condition of fertility.

2. Finding the land in this average state, his utmost ambition may be to keep it in its present condition; or,

3. By *high* farming he may wish to develop all its capabilities, and to increase its permanent productiveness in the greatest possible degree.

The man who aims at the last of these objects is not only the best tenant and the best citizen, but he is also his own best friend. The highest farming, skilfully and prudently conducted, is also the most remunerating.*

But whichever of these three ends he aims at, he will be unable to attain it without a due knowledge of the various manures it may be in his power to apply to his land—what these manures are, or of what they consist—the general and special purposes they are each fitted or intended to serve — which are the most effective for this or that crop, and why they are so — how they are to be obtained in the greatest abundance, and at the least cost —how their strength may be economised — and in what state and at what season of the year they may be most beneficially applied to the land. Such are a few of the questions which the skilful farmer should be ready to ask himself, and should be able to answer.

By a *manure* is to be understood whatever is capable of feeding or of supplying food to the plant. And as plants require earthy and saline as well as vegetable food, gypsum and nitrate of soda are as properly called manures as farmyard dung, bone-dust, or nightsoil.

Manures naturally divide themselves into such as are of *vegetable*, of *animal*, and of *mineral* origin. I shall consider these different kinds of manure in successive chapters.

* A singular illustration of this fact is mentioned as observed in Holstein, where marl is extensively applied to the land. Those fields which are marled yield a much larger produce than before, while the adjoining fields, which are left unmarled, give a *less* return than when all were unmarled; so that the holder of the latter is compelled to improve by marling his fields also.—SPRENGEL.

It is also a curious but important observation, that when light lands, poor in vegetable matter, are reclaimed from a state of waste, they pay better for the manure added to them every succeeding year; that is, the richer in organic matter they become.—VON VOGHT.

SECTION I.—OF THE USE OF VEGETABLE MANURES.

There are two purposes which vegetable manure is generally supposed to serve when added to the soil — it loosens the land, opens its pores, and makes it lighter; and it also supplies organic food to the roots of the growing plant. It serves, however, a third purpose. It yields to the roots those saline and earthy matters, which it is their duty to find in the soil, and which exist in decaying plants in a state more peculiarly fitted to enter readily into the circulating system of new races.

Decayed vegetable matters, therefore, are in reality *mixed manures*, and their value in enriching the land must vary considerably with the *kind* of plants, and with the *parts* of those plants of which they are chiefly made up. This depends upon the remarkable difference which exists in the *quantity* and *kind* of the inorganic matter contained in different vegetable substances, as indicated by the ash they leave, (see pages 64 to 75.) Thus if 1000 lb. of the *sawdust* of the willow be fermented and added to the soil, they will enrich it by the addition of only 4½ lb. of saline and earthy matter, while 1000 lb. of the *dry leaves* of the same tree, fermented and laid on, will add 82 lb. of inorganic matter. Thus, independent of the effect of the organic matter in each, the one will produce a very much greater effect upon the soil than the other.*

There are several states in which vegetable matter is collected by the husbandman for the purpose of being

* It is owing, in part, to this large quantity of saline and other inorganic matters which they contain, that fermented leaves alone form too strong a dressing for flower borders, and that gardeners therefore generally mix them up into a compost.

applied to the land—such as the *green* state, the *dry* state, that state of imperfect natural decay in which it forms *peat*, and the decomposed state of *charcoal*, &c., to which it has been reduced by art.

SECTION II.—OF GREEN MANURING, AND OF THE USE OF SEA-WEED.

When grass is mown in the field, and laid in heaps, it speedily heats, ferments, and rots. But, if turned over frequently and dried into hay, it may be kept for a great length of time without undergoing any material alteration. The same is true of all other vegetable substances—they all rot more readily in the green state. The reason of this is, that the sap or juice of the green plant begins very soon to ferment in the interior of the stem and leaves, and speedily communicates the same condition to the moist fibre of the plant itself. When once it has been dried, the vegetable matter of the sap loses this easy tendency to decay, and thus admits of long preservation.

The same rapid decay of green vegetable matter takes place when it is buried in the soil. Hence the cleanings and scourings of the ditches and hedge-sides form a compost of mixed earth and fresh vegetable matter, which soon becomes capable of enriching the ground. When a green crop is ploughed into a field, the whole of its surface is converted into such a compost — the vegetable matter in a short time decays into a light, black mould, and enriches in a remarkable degree, and fertilises the soil.

This is one reason why the success of wheat after clover, or of oats after lea, depends so much on the ground being well covered when first ploughed up.

1°. *Green manuring.* — Hence the practice of green manuring has been in use from very early periods. The second or third crop of *lucerne* was ploughed in by the ancient Romans—as it still is by the modern Italians. In Tuscany, the *white lupin* is ploughed in—in parts of France, the bean and the vetch — in Germany, *borage* —and upon sandy soils in Holstein, *spurry*. The *Madia sativa* has lately been tried as a green manure in Silesia. It is sown in June, and is ploughed in, when two feet high, in October. Sheep do not eat it; so that if a flock of sheep be turned in, they eat up the weeds and trample down the madia, after which it is easily ploughed in. In a month it is rotten, and the land may be cross-ploughed, and the winter corn sown.

In French Flanders, two crops of *clover* are cut, and the third is ploughed in. In some parts of the United States, the clover is never cut, but is ploughed in as the only manure; in other parts, the first crop is cut and the second ploughed in. In some of the northern States, Indian corn is sown upon poor lands, at the rate of 4 to 6 bushels an acre, and two or sometimes three such crops are turned in during the summer. In north-eastern China, a species of coronilla and a trefoil are specially sown and grown in ridges, as a manure for the rice crop. They are ploughed and harrowed in before the young rice plants are put into the flooded land.

In Sussex, and in parts of Scotland, *turnip* seed has been sown at the end of harvest, and after two months again ploughed in, with great benefit to the land. *Wild mustard*, also, which grows so abundantly as a weed on many of our corn-fields, is not unfrequently raised for ploughing in green. White mustard is sown in Norfolk, and ploughed in as a preparation for wheat; sometimes, also, on the stubble, as a preparation for turnips. It is

said to destroy the wire-worm. *Turnip leaves* and *potato tops* decay more readily and more perfectly, and are more enriching when buried in the green state. It is a prudent economy, therefore, where circumstances admit of it, to bury the potato tops on the spot from which the potatoes are raised.* Since the time of the Romans, it has been the custom to bury the cuttings of the vine stocks at the roots of the vines themselves; and many vineyards flourish for a succession of years without any other manuring. In the Weald of Kent the prunings of the hop-vine, chopped and dug in, or made into a compost and applied to the roots of the hop, give a larger crop, and with half the manure, than when they are burned or thrown away, as is usually done.

Buckwheat, rye, winter tares, clover, and rape, are all occasionally sown in this country for the purpose of being ploughed in. This should be done *when the flower has just begun to open*, and, if possible, at a season when the warmth of the air and the dryness of the soil are such as to facilitate decomposition.

That the soil should be richer in vegetable matter after this burial of a crop than it was before the seed of that crop was sown, and should also be otherwise benefited, will be understood by recollecting (see page 38) that perhaps three-fourths of the whole organic matter we bury has been derived from the air—that by this process of ploughing in, the vegetable matter is more equally diffused through the whole soil, than it could ever be by any merely mechanical means—and that by the natural decay of this vegetable matter, ammonia and nitric acid are, to

* By taking off the blossoms of potatoes—besides the usual increase of crop — the tops keep green till the potatoes are lifted. Thus much green matter is obtained; and if this be made into manure, and applied to the next potato crop, it is said to raise the *largest produce of tubers*.

a greater extent, (pages 28 and 30,) produced in the soil, and its agricultural capabilities in consequence materially increased. Indeed, *a green crop ploughed in is believed, by some practical men, to enrich the soil as much as the droppings of cattle from a quantity of green food three times as great.*

These considerations, while they explain the effect and illustrate the value of green manuring, will also satisfy the intelligent agriculturist that there exist methods of improving his land without the aid either of town or of foreign manures—and that he overlooks an important natural means of wealth who neglects the green sods and the crops of weeds that flourish by his hedgerows and ditches. Left to themselves, they will ripen their seeds, and sow them annually in his fields; collected in compost heaps they will materially add to his yearly crops of corn.

2°. *Use of sea-weed.*—Among green manures, the use of fresh sea-ware deserves especial mention, from the remarkably fertilising properties it is known to possess, as well as from the great extent to which it is employed on all our coasts. The agricultural produce of the Isle of Thanet, in Kent, is said to have been doubled or tripled by the use of this manure; the farms on the Lothian coasts let for 20s. or 30s. more rent per acre when they have a right of way to the sea, where the weed is thrown ashore; * and in the Western Isles the sea-ware, the shell-marl, and the peat-ash, are the three great natural fertilisers, to which the agriculture of this remote region is indebted for the comparative prosperity to which it has in some of the islands already attained.

* In this locality 16 loads of sea-weed are reckoned equal to 20 tons of farmyard manure. In the Island of Lewis 20 tons of sea-ware, which would yield half a ton of kelp, are considered to be ample manure for a Scotch acre.

The common red tangle, which grows farther out at sea, is in some districts preferred as a manure to the other varieties of sea-weed, when applied green or made into compost. At Oban, on the west coast of Scotland, the fishermen bring it in their boats and sell it on the shore at a shilling a cart. One cart is there reckoned equal to two of farmyard dung for raising potatoes. Used alone for this crop, it gives a good return, but generally of inferior quality.* On the south-east coast of Fife, where the sea-weed is laid on the stubble at the rate of 20 carts an imperial acre, ploughed in, and the turnips afterwards raised with half dung, the *clover is said never to fail.* Laid on bean-stubble, and ploughed in, 27 cart-loads gave, in Suffolk, (1819,) three times as much wheat as 5 bushels of salt and 15 loads of farmyard manure per acre.

Sea-weeds decompose with great ease when collected in heaps or spread upon the land. During their decay they yield not only organic food to the plant, but saline matters also, to which much of their efficacy both on the grass and the corn crops is no doubt to be ascribed.

Especially to this saline matter may be ascribed the beneficial influence of sea-weed on garden asparagus, originally a sea-side plant, and upon fruits like raspberries, which contain much alkaline matter.

The value of sea-weed as a manure may be understood from the fact that the *fucus saccharinus* leaves, when dry, 28·6 per cent of ash, and contains 19·26—say 20 per cent—of protein compounds. In its recent state it contains 76 per cent of water, (PAYEN.)

* The potatoes are said to be of better quality when the sea-weed is put into the soil and covered with a layer of earth, upon which the potatoes are to be planted.

SECTION III.—OF MANURING WITH DRY VEGETABLE MATTER.

1. *Straw.*—Almost every one knows that the sawdust of most common woods decays very slowly—so slowly, that it is rare to meet with a practical farmer who considers it worth the trouble to mix sawdust with his composts. This property of slow decay is possessed in a certain degree by all *dry* vegetable matter. Heaps of dry straw when alone, or even when mixed with earth, will ferment with comparative difficulty, and with great slowness. It is necessary, therefore, to mix it, as is usually done, with some substance that ferments more readily, and which will impart its own fermenting state to the straw. Animal matters of any kind, such as the urine and droppings of cattle, are of this character; and it is by admixture with these that the straw which is trodden down in the farmyard is made to undergo a more or less rapid fermentation.

The object of this fermentation is twofold—first, to reduce the particles of the straw to such a minute state of division, that they may admit of being diffused through the soil; and second, that the dry vegetable matter may be so changed by exposure to the air and other agencies, as to be fitted to yield without difficulty both organic and inorganic food to the roots of the plants it is intended to nourish.

Differences of opinion have prevailed, and discussions have taken place, as to the relative efficacy of long and short, or of half fermented and of fully rotten dung. But if it be added *solely* for the purpose of yielding food to the plant, or of preparing food for it, the case is very simple. The more complete the state of fermentation, if not carried too far, the more immediate will be the agency of the ma-

nure—hence the propriety of the application of short dung to turnips and other plants it is desirable to bring rapidly forward; but if the manure be only half decayed, it will require time in the soil to complete the decomposition, so that its action will be more gradual and prolonged.

Though in the latter case the immediate action is not so perceptible, yet the ultimate benefit to the soil, and to the crops, may be even greater, supposing them to be such as require no special forcing at one period of the year. This is easily understood. While it is undergoing fermentation in the farmyard, the straw loses part of its substance—either in the state of gaseous matter, which escapes into the air—or of saline matter, which is washed out in the liquid form. Thus, after complete fermentation, the quantity of matter present is really less, and consequently, when added to the soil, though the *immediate* effect upon the crop be greater, the *whole* effect may also be very considerably less.

This will appear more clearly when it is considered that the quantity of recent dung—mixed straw and cow dung—is by experiment equal on an average to 2 or 2½ times that of the dry food and fodder taken together, while, when fully rotten, the weight of the dung may be no greater than that of the dry food and fodder consumed by the cattle.

Thus it has been found that one ton (20 cwt.) of dry food and straw gives a quantity of farmyard dung which weighs,

When recent, . . .	46 to 50 cwt.
After 6 weeks, . . .	40 to 44 ...
After 8 weeks, . . .	38 to 40 ...
When half rotten, . .	30 to 35 ...
When fully rotten, . .	20 to 25 ...

A part of this loss may, no doubt, be ascribed to the evaporation of a portion of the water of the recent dung; but the larger part is due to an actual escape of the substance of the manure itself. The farmer, therefore, who applies the manure from a given weight of food and straw, in

a fresh state, adds more to his land than if he first allows it to become perfectly fermented. Were he to chop his straw, and put it in as it comes fresh from the field, he would add still more; but its action as a manure would be slower, and while it would beneficially open stiff and heavy soils, it would injure others, by rendering them too light and porous.

2. *Sawdust.*—With a view to this slow amelioration, dry vegetable matter of any kind may, if in a sufficient state of division, be added with benefit to the soil. Even sawdust, applied largely to the land, has been found to improve it,—little at first, more during the second year after it was applied, still more during the third, and most of all in the fourth season after it was mixed with the soil. That any dry vegetable matter, therefore, does not produce an immediate effect, ought not to induce the practical farmer to despise the application to his land—either alone or in the form of a compost—of everything of the kind he can readily obtain. If his fields are not already very rich in vegetable matter, both he and they will be ultimately benefited by such additions to the soil.

Saturated with ammoniacal liquor, or with liquid manure, sawdust has been profitably used, and without further addition, in the raising of turnips. It may also be charred either by burning, or by alternate layers of quick-lime, and thus beneficially applied.

3. *Bran.*—The bran and pollard of wheat are highly recommended as manures. Drilled in with the turnip seed at the rate of 5 or 6 cwt. an acre, at a cost of £1, 2s. 6d., it brought the young plants rapidly forward, and gave one-third more in weight of bulbs than the other parts of the field, which had been treated in the same way in every respect, except that no addition of bran had been made to them. If moistened with urine and slightly

fermented, the action of bran would no doubt be hastened and rendered more powerful.

The husk of the oat, hitherto wasted at many of the oatmeal mills in the north, might also be beneficially fermented and employed as a manure.

4. *Brewers' grains*, though usually given as food to fattening cattle or to milch cows, are by some of the farmers in Norfolk employed as a manure. They are supposed to pay best when mixed with farmyard manure.

5. *Malt-dust*—cummins, or combings—consists of the dried sprouts of barley, which, when the sprouted seed is dried in the process of malting, break off and form a coarse powder. This is found to be almost equal to rape-dust in fertilising power. One hundred bushels of barley yield 105 to 110 of malt and 4 to 5 of dust. In this neighbourhood (Durham) it is sold at one shilling a bushel.

Applied in the dry state, malt-dust decomposes slowly, and from its extreme lightness is applied with difficulty, as a top-dressing. If it be moistened with liquid manure and laid in heaps for a few days till it heat and begin to ferment, it may be used either as a top-dressing for grass, clover, and young corn, or it may be drilled in with the seed. It may also in this state be employed with advantage without any other manure for the turnip or potato crop; but the turnip-seed should not be brought into immediate contact with it in the drills.

Malt-dust leaves, when dry, 8 per cent of ash, and contains 32 per cent of protein compounds, (PAYEN.) This composition explains both its fertilising action when applied to the soil, and its nourishing effects when given to cattle or sheep along with turnips.

6. *Rape-dust.*—It is from the straw of the corn-bearing plants, or from the stems and leaves of the grasses, that the largest portion of the strictly vegetable manures applied to the soil is generally obtained or prepared. But

the seeds of all plants are much more enriching than the substance of their leaves and stems. These seeds, however, are in general too valuable for food to admit of their application as a manure. Still the refuse of some—as that of different kinds of rape-seed after the oil is expressed, and which is unpalatable to cattle—is applied with great benefit to the land. Drilled in with the winter or spring wheat, or scattered as a top-dressing in spring at the rate of 5 cwt. an acre, it gives a largely increased and remunerating return. Applied at a cost of 40s. per acre to wheat, it has been known to increase the produce 10 bushels an acre (from 29 to 39 bushels) and to give one-fifth more straw. Nor is the practice recent, for the application of it in this way, and at a cost of 40s. to 42s. an acre, was common in Norfolk in the time of Arthur Young, (1770,) eighty years ago.

In some districts it is used largely, and without admixture, for the raising of turnips. It is applied with equal success to the cultivation of potatoes, if it be put in the place of a part only of the manure. If used alone it is apt to give very large and luxuriant tops, with only an inferior weight of tubers. It is safer, therefore, to mix it with other manure; and generally it may be substituted for it at the rate of about 1 cwt. of rape-dust for each ton of farmyard manure.

7. *Hemp, poppy,* and *cotton cakes*—the refuse of crushed hemp, poppy, or cotton seed—may be used for similar purposes, and in the same way, as rape-cake.

8. *Cocoa-nut cake,* left by the expressed cocoa-nut, is also a valuable manure, and has alone been found to produce large crops of potatoes. It sells at £5 or £6 a ton.

These different kinds of cake all contain a large percentage of nitrogen, (4 to 4½ per cent,) or, in other words, of protein compounds. These ferment very easily, promote growth rapidly, and give to the manures that contain them peculiar fertilising virtues.

SECTION IV.—OF THE USE OF PEAT, PEAT COMPOST, AND TANNERS' BARK.

1. *Natural peat.*—In many parts of the world—and in none more abundantly, perhaps, than in some parts of our own islands—vegetable matter continually accumulates in the form of peat. This peat ought to supply an inexhaustible store of organic matter for the amelioration of the adjacent soils. We know that by draining off the sour and unwholesome water, and afterwards applying lime and clay, the surface of peat bogs may be gradually converted into rich corn-bearing lands. It must, therefore, be possible to convert peat itself by a similar process into a compost fitted to improve the condition of other soils.

2. *Fermented peat.*—The late Lord Meadowbank, who made many experiments on this subject, found, that after being partially dried by exposure to the air, peat might be readily fermented, and brought into the state of a rich fertilising compost, by the same means which are adopted in the ordinary fermenting of straw. He mixed with it a portion of animal matter, which soon communicated its own fermenting quality to the surrounding peat, and brought it readily into a proper heat. He found that one ton of hot fermenting manure, mixed in alternate layers with two of half-dried peat, and covered by a layer of the same peat, was sufficient to ferment the whole. He observed afterwards, also, that the vapours which rise from naturally fermenting farmyard manure or animal matters, would alone produce the same effect upon peat, placed so as readily to receive and absorb them.

As ammonia is one of the compounds specially given off by putrefying animal substances, it is not unlikely that a

watering with *ammoniacal liquor* would materially prepare the peat for undergoing fermentation. At all events, it seems possible to prepare any quantity of valuable peat compost by mixing the peat with a little soil, and with a still smaller quantity of fermented manure than was employed by Lord Meadowbank, provided the liquid manure of the farmyard be collected into a cistern, and be thrown at intervals, by means of a pump, over the prepared heaps.

After being partially dried, natural peat may be very beneficially employed in absorbing the liquid manure of the farmyard, or in mixing with the contents of the tanks.

3. *Mr Fleming's peat compost.*—Many other ways of working up peat have been suggested, such as adding lime, salt, and other substances, to aid the fermentation. The most successful of these mixtures with which I am acquainted is one which has been used with much advantage on the home farm of Mr Fleming of Barochan. This compost consists of—

Sawdust, or dry earthy peat,	40 bushels.
Coal-tar,	20 gallons.
Bone-dust,	7 bushels.
Sulphate of soda,	1 cwt.
Sulphate of magnesia,	1¼ ...
Common salt,	1½ ...
Quick-lime,	20 bushels.

These materials are mixed together and put into a heap, and allowed to heat and ferment for three weeks, then turned, and allowed again to ferment, when the compost is ready for use.

Compared with farmyard manure and guano, this mixture gave on hay and turnips—

1°. *On hay* per imperial acre.

	Produce.	Cost.
Nothing,	416 stones.	
Guano, 3 cwt.	752 ...	£1 10 0
Compost, 40 bushels,	761 ...	1 0 0

2°. *On turnips*, (Jones' yellow top.)

	Produce.	Cost.
Farmyard manure, 28 yards,	26 tons.	
Guano, 5 cwt. . .	18 ...	£2 10 0
Compost, 64 bushels, .	29 ...	1 11 0

According to these results, this compost is superior even to guano. The experiments, however, require repetition, and the results will no doubt vary with the kind of soil and of crop to which the compost is applied.

4. *Charred peat.*—By being built up and charred or half burned in covered heaps, peat may be obtained in a state in which it is easily reduced to powder. In this powdery state, it has been used alone for turnips, at the rate of 50 bushels an acre, and was found to give as good a crop as 50 carts of farmyard dung. Something of this action, however, may have depended upon the nature of the soil, and upon the kind of peat. Charred peat forms, likewise, an excellent absorbent for the liquids of the farmyard and the stable, and for drying up dissolved bones.

5. *Tanners' bark.*—I may here advert also to the use of tanners' bark, a form of vegetable matter which, like sawdust and peat, is difficult to work up, and is therefore often permitted largely to go to waste. Like peat it may be dried and burned for the ash, which is light, portable, and forms a valuable top-dressing. But the economist will prefer to ferment it in a compost, in the way above described for peat. An occasional watering of the compost with the liquid manure of the farmyard will bring it into a heat, and when the ammoniacal liquor of the gas-works can be procured at a cheap rate, it may be employed for a similar purpose. The hard thick fragments of bark, however, cannot be so soon decomposed as the already finely divided peat, and must be expected therefore to

demand more time. With lime it may, like sawdust or peat, be reduced and charred.

SECTION V.—MANURING WITH ARTIFICIALLY DECOMPOSED VEGETABLE SUBSTANCES — CHARCOAL, SOOT, COAL-TAR, &c.

When wood and other vegetable substances are heated in close vessels they are converted into charcoal. Coal, which is of vegetable origin, deposits in our chimneys, when burned, large quantities of soot; and when distilled in gas-retorts it yields, besides gas, a quantity of coal-tar and other products. All these substances have been tried and recommended as manures.

1°. *Charcoal powder* possesses the remarkable properties of absorbing noxious vapours from the air and from the soil, and of extracting unpleasant impurities as well as saline substances from water, and of decomposing many saline compounds. It also sucks into its pores much oxygen and other gases, from the air. Owing to these and other properties, it forms a valuable mixture with liquid manure, nightsoil, farmyard manure, ammoniacal liquor, or other rich applications to the soil. It is even capable itself of yielding *slow* supplies of nourishment to living plants; and it is said in many cases, even when unmixed, to be used with advantage as a top-dressing in practical agriculture.* In moist charcoal the seeds of the gardener are found to sprout with remarkable quickness and certainty; but after they have sprouted, they do not continue to grow well in charcoal alone. Drilled in with

* This may no doubt be in part owing to its aiding the production, as all *porous* substances do, of ammonia in its interior, and hence of apocrenate of ammonia (p. 23) in the soil, but in part also to its power of decomposing other substances.

the seed, charcoal powder is said greatly to promote the growth of wheat.

2°. *Soot*, whether from the burning of wood or of coal, consists chiefly of a finely divided charcoal, possessing the properties above mentioned. It contains, however, ammonia, gypsum, nitric acid, and certain other substances in considerable quantity, to which its well-known effects upon vegetation are chiefly to be ascribed. In many localities it increases the growth of the grass in a remarkable degree, and as a top-dressing to wheat and oats, it sometimes produces effects equal to those which follow the use of the nitrates of potash or soda.*

Thus wheat and oats dressed with soot, in comparison with undressed, gave the following return of grain —

	Wheat.	Oats.
Undressed, . .	44 bushels.	49 bushels.
Dressed, . .	54 ...	55 ...
Increase, .	10	6

It acts also upon root crops—56 bushels of soot mixed with 6 of common salt having produced larger crops of carrots than 24 tons of farmyard manure, with 24 bushels of bones.†

I have lately examined several varieties of soot, and find that it contains from 18 to 48 per cent of mineral matter, consisting of earthy substances from the coal carried up into the chimney by the draught, and of gypsum and sulphate of magnesia derived from the lime of the flue and the sulphur of the coal. It contains besides from 1 to 2 per cent of ammonia, chiefly in the state of sulphate. These proportions of ammonia, calculated in the state of sulphate of ammonia, are equal to from 5½ to

* *Journal of the Royal Agricultural Society of England*, ii. p. 259.

† *Ibid.* iv. p. 270.

12 per cent of the whole weight of the soot. It is not wonderful, therefore, that its effects should resemble, and even rival, those of the nitrate of soda and of the sulphate of ammonia.

When applied to grass in spring it is said to give a peculiar bitterness to the pasture, and even to impart a taste to the milk. Hence, in large towns, the cow-feeders of the milk-dairies are unwilling to purchase early grass which has been manured with soot.

3°. *Coal-dust.*—In the county of Durham the dust of common coal, such as is sifted out at the mines as too small for burning, has been spread upon poor, cold, arable land, and as a top-dressing upon old pastures, with manifest advantage. Something will, no doubt, depend both upon the quality of the coal and upon the kind of land to which it is applied.

4°. *Coal-tar* applied to the wheat-stubble with a water-cart, at the rate of 180 gallons to the imperial acre, and allowed to remain two or three months before it is ploughed in, is said greatly to benefit the after crop of roots. It has been tried on a sandy loam, and on a deep clay. It has also been used in the form of compost.

SECTION VI. — RELATIVE FERTILISING AND MONEY VALUES OF DIFFERENT VEGETABLE MANURES.

There are two principles on which the relative values of different vegetable substances, as manures, may be estimated; —*first*, by the relative quantity and kind of *inorganic matter* they respectively contain; and *second*, by the relative proportions of *nitrogen* present in each.

1. Valued according to the *quantity* of inorganic matter

ey contain, the worth of the several kinds of straw, y, &c., would be represented by the following numbers: *ton weight* of each substance, when made into manure provided nothing is washed out by the rains—will ;urn to the soil the following quantities of inorganic ıtter in *pounds*:—

Wheat-straw,	70 to 360
Oat-straw,	100 to 180
Hay,	100 to 200
Barley-straw,	100 to 120
Pea-straw,	100 to 110
Bean-straw,	100 to 130
Rye-straw,	50 to 100
Dry potato-tops,	400
Dry turnip-tops,	370
Rape, and other cakes,	120
Malt-dust,	180
Dried sea-weed,	560

nerally, perhaps, these numbers will give the reader a erably correct idea of the relative *permanent* effects of e above different kinds of vegetable matter, when laid on the soil. But a reference to the facts stated in . 69 to 80, in regard to the *quality* of the inorganic ıtter contained in plants, will satisfy him that the effect these manures on particular crops is not to be judged solely by the absolute *quantity* of earthy and saline ıtter they contain. What the turnip-top, for example, the bean-stalk, returns to the soil, may not be exactly ıat will best promote the growth of wheat.

2. On the other hand, if the fertilising value of vege-ble substances is to be calculated from the relative quan-ies of nitrogen they severally contain, we should place əm in the following order;—the number opposite to :h substance representing that weight of it in pounds ıich would produce the same effect as 100 pounds of myard manure, consisting of the mixed droppings d litter of cattle. (BOUSSINGAULT.)

	Equivalent quantities in pounds.
Farmyard manure,	100
Wheat-straw,	80 to 170
Oat-straw,	150
Barley-straw,	180
Buckwheat-straw,	85
Pea-straw,	45
Wheat-chaff,	50
Green grass,	80
Potato-tops,	75
Fresh sea-weed,	80
Dried sea-weed,	20
Bran of wheat or Indian corn,	26
Malt-dust,	13
Rape, and other cakes,	8
Fir sawdust,	250
Oak sawdust,	180
Coal-soot,	20 to 30

This table again presents the same substances in a somewhat different order of value; showing, for example, not only that such substances as rape-dust, malt-dust, and soot, should produce a much more remarkable effect upon vegetation than the same weight even of farmyard manure, but also that certain dry vegetables, such as bran, chaff, and pea-straw, will yield, when not unduly fermented, a more enriching manure than the straw of barley, oats, or wheat. It agrees also with the known effect of green manuring upon the land, since 80 *pounds of meadow grass ploughed in should, according to the table, be equal in virtue to* 100 *of farmyard manure.*

Some writers ascribe the *entire* action of these manures to the nitrogen they contain. This, however, is taking a one-sided view of their real natural operation. The nitrogen, during their decay, is liberated chiefly in the form of ammonia, — a comparatively evanescent substance, producing an immediate effect in hastening or carrying farther forward the growth of the plant, but not remaining permanently in the soil. The reader,

therefore, will form an opinion consistent alike with theory and with practice, if he concludes—

1. That the *immediate* effect of vegetable manures in hastening the growth of plants is dependent, in a great degree, upon the quantity of nitrogen they contain and give off during their decay in the soil; but—

2. That their *permanent* effect and value is to be estimated chiefly by the quantity and quality of the inorganic matter they contain—of the ash they leave when burned.

The effect of the nitrogen may be nearly expended in a single season; that of the earthy and saline matters may not be exhausted for several years.

Nor is the carbon of vegetable substances without its important uses to vegetation. From the statements contained in the earlier chapters of the present work—especially in reference to the production of ammonia and nitric acid in the soil, through the agency of decaying carbonaceous matter—it may be inferred that, however much influence we may allow to the nitrogen and to the earthy matter of plants in aiding the growth of future races, the soundest view is that which considers *each of the elements present in decayed or decaying plants to be capable either of ministering to, or of preparing food for, such as are still alive.* We may not be able as yet to estimate the precise importance of each element to any particular kind of crop or soil, or so to adjust the quantities of each in our manures, as to promote the growth of that crop upon that soil, in the greatest possible degree, yet the principle itself is a sound one, and will hereafter guide us to safe and correct results.

CHAPTER XIV.

Animal manures.— Flesh, fish, shell-fish.—Insects.—Blood.—Animalised charcoal.—Skin, horn, hair, wool.—Woollen rags.—Shoddy.—Horn-sawdust, and hoof parings.—Cause of the fertilising influence of these manures.—Composition and use of bones and horn-flints.—Preparation of dissolved bones. — Comparative experiments with crushed and dissolved bones. — Why solution in acid makes bones more active.—Comparative action of flesh, blood, horn, woollen rags and bones.—Use of the liquid excretions of animals.—Urine of man, the cow, the horse, and the pig. — Construction of liquid-manure tanks.—Urate.—Sulphated urine.

The animal substances employed as manures consist chiefly of the flesh, blood, bones, horns, and hair of sea and land animals, and of the solid and liquid excrements of land animals and birds.

SECTION I.—OF FLESH, FISH, BLOOD, AND SKIN, AND OF THEIR USE AS MANURES.

Animal substances, in general, act more powerfully as manures than vegetable substances; it is only the seeds of plants which can be at all compared with them in efficacy.

1. The *flesh* of animals is rarely used as a manure, except in the case of dead horses or cattle which cannot be used for food.

2. *Fish* are, in this country, chiefly applied in the form of the refuse of the herring and pilchard fisheries, though

occasionally such shoals of sprats, herrings, dog-fish, and even mackerel, have been caught on our shores, as to make it necessary to employ them as manure. These recent animal substances are found to be, for the most part, too *strong* when applied directly to the land; they are usually, therefore, made into a compost, with a large quantity of soil. Five barrels of fish, or fish refuse, made into twenty loads of compost, will be sufficient for an acre.

On the coast of Norfolk, large quantities of sprats are used as a manure for the turnip crop. They are sold for about 8d. a bushel. A ton and a half, mixed with twelve to fifteen cwt. of mould taken from the head of the field, makes a compost which is sufficient for an imperial acre, and is said never to fail. On the shores of Aberdeenshire, dog-fish are caught and applied as a manure.

In Rhode Island and the adjoining States, considerable quantities of manure are made by mixing the fish called *menhaden*, of which large numbers are taken in the bays, with peat or swamp mud, in the proportion of one load of fish to ten of peat or mud. As many as 750 tons of this fish have been taken at a single haul, and sold to the farmers at about 2s. 6d. the thousand fish, or waggon-load.* On the coasts of Connecticut large quantities of fish, called white fish, are caught and sold for manure, at the rate of about a dollar (4s.) a thousand, weighing 15 or 20 cwt. They are either laid on the land and ploughed in, or are made into a compost. In the north of China, prawns and other kinds of fish are collected and employed for manuring purposes.

The refuse of the fish oils, of the fat of animals that has been melted for the extraction of the tallow, of skins

* See the Author's *Notes on North America*, vol. ii. p. 231.

that have been boiled for the manufacture of glue—as also horns, hair, wool, woollen rags, and all similar substances, when made into composts—exercise, in proportion to their weight, a much greater influence upon vegetation than any of the more abundant forms of vegetable matter.

3. *Shell-fish*, when they abound on our coasts, have been found to be capable of economical application to the land, even for raising turnips and potatoes. They are mixed with a little earth into a rich compost, and allowed slightly to ferment. If the means of crushing them be at hand, their value is by this process considerably increased. On the northern shores of the Solway, near Annan, the common mussel is found in such quantities in some places, that, when the tide recedes, a cart-load can be raked out of the sand in so short a time as to make it a very economical manure. The Rev. Mr Gillespie of Cummertrees informs me, that 700 cart-loads were collected and applied to the raising of turnips during the year 1844. They are used, without other manure, at the rate of about 50 bushels to the Scotch acre. On the coasts of Lincolnshire, also, they are met with in some places in large quantities, and collected for use as a manure.

4. Even *the bodies of insects* in many parts of the world form important manures. In warm climates, a handful of soil sometimes seems almost half made up of the wings and skeletons of dead insects: in Hungary and Carinthia the peasant occasionally collects as many as 30 cart-loads of dead marsh-flies in a single year; and in the richer soils of France and England, where worms and other insects abound, the presence of their remains in the soil must aid its natural productiveness.

5. *Blood* is in this country very seldom applied to the

land directly. Like the other parts of animals, however, it makes an excellent compost. In Northamptonshire, such a compost is made by mixing about 50 gallons of blood with 8 bushels of peat-ashes and charcoal powder, and allowing the mixture to stand for a year or two. On light soils, this compost raises excellent turnips when applied alone, at the rate of 6 quarters (48 bushels) per imperial acre—or of 2 quarters with 12 tons of farmyard dung. As a top-dressing to young wheat, 20 or 30 bushels an acre greatly increase the crop. On heavy and wet lands its effects are less perceptible. In that part of England the blood is contracted for at the rate of 3d. a gallon. In some countries the blood is dried, and in the state of powder is applied as a top-dressing to the growing crops. In this state it is sold in Paris at about 8s. a cwt.—a moderate price, if it be tolerably dry. Samples prepared in London, and containing still 22 per cent of water, have also been valued at £8 or £9 a ton. But this mode of using blood is not very widely adopted.

6. *Animalised charcoal.*—As blood comes from the sugar refineries, however—in which, with lime-water and animal charcoal, it is employed for the refining of sugar—it has obtained a very extensive employment, especially in the south of France. This animal black, or *animalised charcoal*, as it is sometimes called, contains about 20 per cent of blood, and has risen to such a price in France that the sugar refiners actually sell it for more than the unmixed blood and animal charcoal originally cost them. This has given rise to the manufacture of artificial mixtures of charcoal, fecal matters, and blood, which are also sold under the name of animalised charcoal. A great disadvantage attending the use of these artificial preparations is, that they are liable to be adulterated, or, for cheapness, prepared in a less efficient manner.

7. *Skin.*—Fragments of skin are sometimes used as a manure. The parings of skins from the tan-works are boiled by the glue-makers, and the insoluble refuse is sold as a manure. This refuse, in the form of compost, ought to nourish the crops very much. When used alone for potatoes, it is said to make them *waxy* on soils where, with other manures, they grow *mealy* and *dry*.

SECTION II.—OF HAIR, WOOL, WOOLLEN RAGS, SHODDY, HORN-SAWDUST, AND HOOF-PARINGS.

1. *Horn*, *hair*, and *wool*, depend for their efficacy precisely on the same principles as the blood and flesh of animals. They differ chiefly in this, that they are *dry*, while blood, flesh, and fish contain about 80 per cent of their weight of water. Hence, one ton of horn-shavings, of hair,* or of dry woollen rags, ought to enrich the soil as much as 4 to 5 tons of blood. In consequence, however, of their dryness, the horn and wool decompose much more slowly than the blood. Hence the effect of soft animal matters is more immediate and apparent, while that of hard and dry substances is less visible, but continues for a much longer period of time.

2. *Woollen rags*, when made into a compost and fermented, form an excellent manure for potatoes or turnips. In the hop countries, they are buried at the roots of the hop plants with great advantage. They sell at about £5 a ton. On the sandy land in Wiltshire, they are frequently used as a manure for turnips.

3. *Shoddy*, or mill-waste—the waste of the woollen and cloth mills of Yorkshire—is nearly the same thing as hair

* In China, the hair, which every ten days is shaven from the heads of the entire population, is collected and sold for manure throughout the empire.

and woollen rags. It sells at about £2 a ton, and is extensively used by the farmers of Kent and Northampton.

4. *Horn-sawdust*, and *hoof-parings*.—The small dust, parings, turnings, and siftings of horn from the shops of the comb-makers, as well as the hoofs of cattle, are now sold to the prussiate of potash manufacturers at the rate of about £2 a ton. If they were free from admixture, they should be worth to the farmer about the same price as woollen rags. They are usually mixed, however, with much sand and dust—amounting sometimes to 50 or 60 per cent of their whole weight. In this state they are not worth more than two-fifths of the price of *dry* hair or woollen rags. They may be used instead of bones for the turnip or potato crop, but should be made into a fermented compost before they are employed as a top-dressing.

SECTION III.—CAUSE OF THE FERTILISING INFLUENCE OF THE ABOVE ANIMAL MANURES.

The fertilising influence of the parts of animal bodies, described in the preceding sections, depends mainly upon their consisting, for the greater part, of substances very rich in nitrogen. Thus—

	Percentage of nitrogen.
Dry blood, flesh, and fish, contain about . .	15½
Dry skin, hair, wool, horns, and hoofs, . .	16 to 17½

But these two classes of substances differ much in the quantity of water they contain—

	Percentage of water.
Blood, fish, and flesh, contain . . .	78 to 82
Hair, wool, and horn, ...	10 to 15

Skin and hoofs vary much in dryness, and therefore the average proportion of water in them cannot be estimated.

The special differences of the above substances as ma-

nures depend mainly upon those differences in the proportion of water. Blood, fish, and flesh decompose rapidly, act quickly, and promote growth speedily. Wool, hair, and horn take a long time to rot, are not so well adapted, therefore, for promoting speedy growth, but by their gradual decay are better fitted to afford prolonged nourishment to a crop which continues long in the ground, or permanently to enrich a soil which has been exhausted by too severe cropping.

The mineral matter contained in these substances is small in quantity, and therefore of comparatively little influence upon their manuring value. Dry blood and flesh leave about 4 per cent of ash, while wool, hair, and horn leave only 1 or 2 per cent. The ash of flesh and fish consists almost entirely of phosphates, and that of blood in great part of common salt. This may influence their respective action upon plants—as the fact that hair contains 5 per cent of sulphur may also modify the action of this substance as a manure. (See p. 219.)

SECTION IV.—COMPOSITION OF BONES AND THE PITH OF HORNS, AND THEIR VALUE AS MANURES.

1. *Bones*, while they resemble hair and horn in being dry, differ from them in containing a large quantity of earthy matter, and hence they introduce a new agent to aid their effect upon the soil. Thus, the bones of the cow consist in 100 lb. of—

Phosphate of lime, ...	55½
Phosphate of magnesia, ...	2
Soda and common salt, ...	2½
Carbonate of lime, ...	3¾
Fluoride of calcium, ...	3
Gelatine (the substance of *horn*,) . .	33¼
	100.

While 100 lb. of dry bone-dust, therefore, add to the soil as much *organic* animal matter as 33 lb. of horn, or as 300 to 400 lb. of blood or flesh, they add at the same time two-thirds of their weight of inorganic matter, consisting of lime, magnesia, soda, common salt, and phosphoric acid (in the phosphates)—all of which, as we have seen, must be present in a fertile soil, since the plants require a certain supply of them all at every period of their growth. These substances, like the inorganic matter of plants, may remain in the soil, and may exert a beneficial action upon vegetation after all the organic or gelatinous matter has decayed and disappeared.

2. *Horn flints*, or *piths*, resemble bone very much in composition. They contain a little more animal matter, and from their softness and porosity are more difficult to crush in the mill. For the same reason, however, they decay more rapidly in the soil, and act more immediately than bones. They boil down, however, more readily than bones, and are therefore largely used for making the size used in stiffening calicoes. For this purpose they are sold by the comb-makers at about £4 a ton.

When they are not in demand for this purpose they may be very usefully employed as a manure.

A sample of the pith, as it is sold in the market, gave to Professor Norton in my laboratory—

Water, (lost at 212°,) . .	10.31
Phosphates of lime and magnesia, .	46.14
Carbonate of lime, . . .	7.71
Gelatine, (organic matter,) . .	35.84
	100.

SECTION V.—PREPARATION OF DISSOLVED BONES. COMPARATIVE EXPERIMENTS WITH CRUSHED AND DISSOLVED BONES. WHY THIS SOLUTION MAKES BONES MORE ACTIVE.

For the purpose of bringing bones into a state in which the substances they contain can be more readily taken up by the roots of plants, and at the same time more uniformly distributed through the soil, the method has been adopted of dissolving them in sulphuric acid. For this purpose, the bone-dust is mixed with one-half its weight, and sometimes with its own weight of sulphuric acid (the oil of vitriol of the shops,) previously diluted with from one to three times its bulk of water. Considerable effervescence takes place at first, from the action of the acid upon the carbonate of lime in the bones; but, after two or three days, with occasional stirring, the bones are entirely dissolved or reduced. The solution or paste may now be dried up with charcoal powder, with dried or charred peat, with sawdust, or with fine vegetable soil, and applied with the hand or with the drill to the turnip crop; or it may be diluted with 50 times its bulk of water, and let off into the drills with a water-cart. Applied either way, the effect is much more striking than when the same weight of bone-dust is applied in the ordinary form. Thus—

a. At Gordon Castle (Mr Bell) the following results were obtained :—

Manure per Imperial Acre.	Cost.	Produce of Bulbs, Dale's Hybrid.
14 yards farmyard dung, 8 bushels bones,	£3 0 0	12 tons.
3 cwt. guano,	1 17 0	11¾ ...
16 bushels bones,	1 16 0	11 ...

Manure per Imperial Acre.	Cost.	Produce of Bulbs, Dale's Hybrid.
2 bushels bones, 83 lb. sulphuric acid, 400 gallons water,	£0 11 6	12⅕ ...
8 bushels bones, 83 lb. sulphuric acid—sown with the hand,	1 5 0	11 ...

The largest produce was here obtained, when the dissolved bones were applied with a water-cart, and at a cost of eleven shillings per acre.

b. Again, on the farm of Sheriffstoun in Morayshire, (Mr M'William,) the following comparative results were obtained in 1843 :—

1. *Swedish Turnips.*

Manures.	Cost per Acre.	Produce in Bulbs per Imperial Acre.
75 lb. (1⅗ bushels) bones, 46 lb. acid, 400 gallons water,	£0 9 3	17½ tons.
The same with 200 gallons water.	0 9 3	18½ ...
440 lb. (9½ bushels) bones, 28 lb. of acid,	1 4 9	17 ...

2. *Common Turnips.*

170 lb. (3⅕ bushels) bones, 92 lb. acid, 400 gallons water,	£0 17 6	16 tons.
16 bushels bones, 46 lb. acid, 10 gallons water,	2 2 0	13½ ...

In all these cases the smaller quantity of bones, when dissolved in acid and applied in a liquid state, gave a heavier return of bulbs than the larger quantity when drilled in dry. Even the watering of the large quantity of bones with a portion of acid, did not make their effect on the crop equal to that of the small quantity of dissolved bones.

Mr Hannam obtained, by the use of crushed and dissolved bones upon turnips, the following results :—

Bones.		Tons. cwts.	
16 bushels, crushed, gave	.	10 3	per imperial acre.
2 ... dissolved, ...	.	9 12	...
2	.	11 15	...
4	.	12 11	...
4	.	14 6	...
4	.	14 11	...
8	.	13 15	...
8	.	15 2	...
8	.	16 1	...

We can explain this superior action of dissolved bones by the fact, that the dissolving separates their particles completely from each other, diffuses them more completely through the soil, and presents them to a larger surface of the turnip roots, and in a state in which they can be more readily absorbed. The sulphuric acid also may have some effect, since we know that sulphur, in some form, is necessary to the growth of all our crops. I have indeed been informed of a case at Balcarras, in Fifeshire, where diluted sulphuric acid applied alone to the drills produced an excellent crop of turnips; and of another in Dumfriesshire, where steeping the seed-corn in diluted sulphuric acid added many bushels to the crop of barley.

Though the immediate effect of a small quantity of bones on the first crop is made so much greater by this mode of applying them, it is not to be expected that the effect upon the after crops should be as beneficial as when a larger quantity of bones is applied in the ordinary method.

SECTION VI.—COMPARATIVE ACTION OF FLESH, BLOOD, HORN, WOOLLEN RAGS, AND BONES.

From what has been stated in the preceding sections the reader will gather these general conclusions—

1. That animal substances which, like flesh and blood,

contain much water, decay rapidly, and are fitted to operate *immediately* and powerfully upon vegetation, but are only temporary or evanescent in their action. (P. 214.)

2. That when dry, as in horn, hair, and wool, they decompose — and consequently act — more slowly, and continue to manifest an influence, it may be, for several seasons.

3. That bones and horn flints act like horn, in so far as their animal matter is concerned, and, like it, for a longer or shorter time, according as they have been more or less finely crushed; but that they ameliorate the soil by their earthy matter for a still longer period—permanently improving the condition, and adding to the natural capabilities of the land.

4. That the action of bones may be rendered more immediate and striking by bringing them into a minute state of division, — as by dissolving them in diluted sulphuric acid, or by fermenting them in a mixture of moist sand or soil—but that, like flesh and blood, their effect, by that means, is likely to be rendered less permanent.

SECTION VII. — OF THE URINE OF ANIMALS, AND THE MEANS OF PRESERVING AND APPLYING IT. URATE. SULPHATED URINE, &c.

Practical men have long been of opinion that the digestion of food, either animal or vegetable, — its passage through the bodies of animals, — enriches its fertilising power, weight for weight, when added to the land. Hence in causing animals to eat up as much of the vegetable productions of the farm as possible — of the straw and turnip-tops, for example, as well as of the grain and bulbs —it is supposed that not only is so much food saved, but

that the value of the remainder in fertilising the land is greatly increased. In a subsequent section we shall see how far theory serves to throw light upon these opinions.

The digested animal substances usually employed as manures are—the urine of man, of the cow, and of the sheep; the solid excrements of man (nightsoil,) of the horse, the cow, the sheep, and the pig, and the droppings of pigeons and other birds. The liquid manures act chiefly through the saline substances which they hold in solution, while the solid manures contain also insoluble matters which decay slowly in the soil, and there become useful only after a time. The former, therefore, will influence vegetation more powerfully at first; the action of the latter will be less evident, but will continue to be sensible for a much longer period of time.

1. *The urine of man.*—Human urine consists, in 1000 parts, of—

Water, ...	932
Urea, and other organic matters containing nitrogen,	49
Phosphates of ammonia, soda, lime, and magnesia, .	6
Sulphates of soda and ammonia, ...	7
Sal-ammoniac, and common salt, ...	6
	1000

1000 lb. of urine, therefore, contain 68 lb. of dry fertilising matter of the richest quality, worth, *at the present rate of selling artificial manures in this country*, at least 10s. a cwt. As each full-grown man voids about 1000 lb. of urine in a year, the national waste incurred in this form amounts, at the above valuation, to 6s. a head. And if 5 tons of farmyard manure per acre, added year by year, will keep a farm in good heart, 4 cwt. of the solid matter of urine would probably have an equal effect; or the urine alone discharged into the rivers by a population of 10,000 inhabitants would supply manure to a farm of 1500 acres, and would yield a return of 4500

quarters of corn, or an equivalent produce of other crops. Mr Smith of Deanston considered the urine of two men to be a sufficient manuring for an acre of land, and that when mixed with ashes it would produce a fair crop of turnips.*

An important chemical distinction exists between the urine of man and that of the cow, the horse, and the sheep. It contains, as is shown in the previous page, about 6 per cent of phosphates, while these compounds are entirely absent from the urine of the other animals. The presence of the phosphoric acid, contained in these phosphates, adds very much to the manuring value of human urine.

If milk of lime be mixed with fermenting human urine, this phosphoric acid is precipitated with a portion of the animal matter. Dr Stenhouse found a precipitate of this kind, when dried at 212° F., to contain 40 per cent of phosphoric acid and of organic matter, including about 1 per cent of ammonia. By the use of this method, an important part of the fertilising ingredients of human urine may be separated in a solid state. It has recently been adopted with some success for the purpose of separating the fertilising matters contained in sewage water.

2. *Pig's urine.*—The urine of the pig resembles that of man, in containing a considerable proportion of phosphoric acid. In this respect it is more valuable as a manure than those of the horse, the cow, and the sheep.

3. *The urine of the cow* is said to contain less water than that of man, though of course much must depend upon the kind of food with which it is fed. Considering, then, the large quantity of liquid manure that is yielded by the cow (1200 or 1500 gallons a-year,) we may safely estimate the solid matter given off by a healthy animal

* *Report of Committee on Metropolitan Sewerage.*

in the form of urine in twelve months, at about 1000 lb. in weight—worth, *if it were in the dry state*, from £4 to £5 sterling. In the *liquid* state, the urine of one cow, collected and preserved as it is Flanders, is valued in that country at about £2 a-year. Any practical farmer may calculate for himself, therefore, how much real wealth, taking it even at the Flemish value, is lost in his own farmyard—how much of the natural means of reproductive industry passes into his drains, or evaporates into the air.

This liquid manure is very valuable, when collected in tanks, for watering the manure and compost heaps, and thus hastening their decomposition. It may also be sprinkled directly upon the fields of grass or of clover, and upon the young corn, — or the young green crop (turnips, &c.) may be watered with it, with the best effects. It must, however, be permitted to stand till fermentation commences, and must afterwards be diluted with a considerable quantity of water, before it will be in the best condition for laying upon the land. This dilution, indeed, where the receiving tanks are large enough, should be made at an earlier period, for it has been found that, when unmixed with water, cows' urine, which is six weeks old, contains only *one-sixth* part of the ammonia retained by the same urine when it has been previously diluted with an equal bulk of water. Sulphuric acid may also be added to fix the ammonia.*

* To saturate and fix the whole of the ammonia *capable* of being formed in the urine of a single cow of average size, would require about 700 lb. of the common strong sulphuric acid of the shops, or nearly 60 lb. a-month, costing 9s. One-third or one-fourth of this quantity, however, added to the liquid-manure tank, would be sufficient to prevent any very sensible loss. Mr Kinninmonth found 750 gallons of cows' urine so treated, with about 15 lb. of acid, equal in increasing the produce of hay to 2½ cwt. of guano, or 1 cwt. of nitrate of soda.

4. *Of the construction of liquid-manure tanks.*—There are four practical points which are worthy of attention in the construction of tanks for liquid manure.

a. They ought to be well puddled with clay behind the stone or brick work, to prevent any loss or escape of the liquid.

b. They ought to be covered over, and the closer the better. In Germany they are usually vaulted. From close tanks the sun, rain, and air are in a great measure excluded, and the fermentation is slower, and the loss of ammonia in consequence considerably less.

c. They should be divided by a wall, into at least two compartments, capable of holding each a two or three months' supply. When the first of these is full, the stream is turned into the second, and by the time it is also full, the contents of the first are *ripe*, or in a fit state for putting upon the land. The liquid ought always to be in a state of fermentation before it is applied either to grass or to any other crop. This double tank also enables the farmer to collect and preserve his liquid during the three months of winter, when it cannot be applied, and to have a large supply in a fit state for putting on when the young grass or corn begins to shoot.

The liquid as it comes from the cattle ought to be mixed in the tank with at least its own bulk of water. By this means a considerable loss of ammonia is prevented which would otherwise escape from the urine during fermentation; and it is prevented from burning the grass, which in very dry seasons it is apt to do when put on without dilution. This necessarily involves larger cisterns, and more labour in carrying out the liquid; but experience seems to say that the additional profit exceeds considerably the additional expense.

5. *Urate.*—Among other methods of obtaining the

virtues of animal urine in a concentrated form, burnt gypsum is mixed with it in the state of powder in the proportion of 10 lb to every 7 gallons, allowing the mixture, occasionally stirred, to stand some time, pouring off the liquid, and drying the gypsum. This is sold by manure manufacturers under the name of *urate*. It never can possess, however, the virtues of the urine, since it does not contain the soluble saline substances, which the gypsum does not carry down with it. Except the gypsum, indeed, 100 lb. of urate contain no greater weight of saline and organic matter than ten gallons of urine. If it be true, then, as the manufacturers state, that 3 or 4 cwt. of urate are sufficient manure for an acre, the practical farmer will, I hope, draw the conclusion,—not that it is well worth while to venture his money in buying this urate, and trying it upon his land,—but that a far more promising adventure will be to go to some expense in saving his own liquid manure, and after mixing it, if he think proper, with the burned gypsum, to lay it abundantly upon all his fields.

6. *Sulphated urine.*—A better method than that of using gypsum has been lately adopted by several manure manufacturers. They mix as much sulphuric acid with the urine as is sufficient to combine with and fix the whole of the ammonia which may be produced during the decomposition of the urine. The mixture is then evaporated to dryness, and is sold and applied to the land in the state of a dry powder.

This sulphated urine, containing as it does all the saline substances of the liquid urine, with the addition of sulphuric acid, ought to prove a most valuable manure. If prepared from human urine, it will promote the growth of nearly all crops; but, from the sulphuric acid it contains, it may exercise a special influence on beans, peas,

and clovers. As a top-dressing it may be applied alone; but when used for root crops, it ought to be mixed with and to take the place of not more than one-half of the farmyard manure usually applied. Used in this way, at a cost of £2 an acre, Mr Finnie of Swanston obtained, in 1843, four tons of turnips per imperial acre more than from an equal cost of guano.

As a top-dressing for wheat, and probably also for other corn crops, this sulphated urine may be advantageously mixed with an equal weight of sulphate of soda or of common salt, with at least as much wood ashes, if they can be had, and with half its weight of dissolved bones. The soda salts are especially desirable where the land lies remote from the sea.

7. *Ammoniaco-magnesian phosphate.*—Boussingault fixes the ammonia and phosphoric acid of human urine by adding to it, after it has acquired an ammoniacal odour, a solution of sulphate or muriate of magnesia, when the double phosphate of magnesia and ammonia falls to the bottom of the liquid. About 7 lb. of this salt are obtained from 100 lb. of urine; and it has been ascertained to possess powerful fertilising properties.*

* In reference to liquid manures, I strongly recommend to my readers, the "Minutes of Information collected on the Practical Application of Sewer Water, and Town Manures, to Agricultural Purposes," published by the General Board of Health.

CHAPTER XV.

Animal manures continued.—Solid excretions or droppings of animals. —Nightsoil.—Poudrette.—Taffo.—Cow, horse, and pigs' dung.— Droppings of birds.—Pigeons' dung.—Guano.—African and American varieties.—Their composition, and fertilising values.—Their durability.—Adulteration of, how to test or select a good sample, quantity imported, and value to the nation.

THE solid excretions of animals are not less valuable as manures than their urines, and in almost every country are much more generally employed.

SECTION I.—OF NIGHTSOIL, POUDRETTE, AND TAFFO; AND OF COW, HORSE, AND PIGS' DUNG.

1. *Nightsoil* is probably the most valuable of all the solid animal manures. It varies in richness with the food of the inhabitants of each district,*—chiefly with the quantity of animal food they consume,—but when dry, few other solid manures, weight for weight, can be compared with it in general efficacy. It contains much soluble and saline matter, and as it is made up from the constituents of the food we eat, of course it contains

* This is said to be so well known in some of the towns in the centre of Europe, where a mixed population of Protestants and Roman Catholics live together, that the neighbouring farmers give a larger price for the house-dung of the Protestant families. In Persia, the nightsoil of the Russian families is, for a similar reason, preferred to that of the less flesh-eating Mahometans.

most of those elementary substances which are necessary to the growth of the plants on which we principally live.

2. *Poudrette.*—Attempts have been made to dry nightsoil so as to render it more portable,—to destroy its unpleasant smell, so as to reconcile practical men to a more general use of it,—and, by certain chemical additions, to prevent the waste of ammonia and other volatile substances, which are apt to escape and be lost when this and other powerful animal manures begin to putrefy. In Paris, Berlin, and other large cities, the nightsoil, dried first in the air with or without a mixture of gypsum or lime, then upon drying-plates, and finally in stoves, is sold under the name of *poudrette*, and is extensively exported in casks to various parts of the country. It is said to be equal in efficacy to 30 times its bulk of horse or street manure, and is applied at the rate of from 15 to 35 bushels an acre.

In London, also, nightsoil is dried with various admixtures; and in some of our other large towns an *animalised charcoal* is prepared by mixing and drying nightsoil with gypsum and ordinary wood charcoal, in fine powder. Charred peat would answer well for such a purpose.

Few simple and easily attainable substances would make a better compost with nightsoil, and more thoroughly preserve its virtues, than half-dried peat, sawdust, or rich vegetable soil, mixed with more or less marl or gypsum. It is impossible to estimate the proportion of waste which this valuable manure undergoes by being allowed to ferment, without mixture, in the open air.

3. *Taffo.*—In China nightsoil is kneaded into cakes with clay, which are dried in the air, and, under the name of *taffo*, form an important article of export from all the large cities of the empire. In Persia it is dried in the sun

and powdered. Mixed with twice its bulk of dry soil, it is then used for raising the finest melons.

4. *Cow, horse, and pigs' dung.* So much of the saline and soluble organic matters in the excretions of the cow pass off in the liquid form, that its dung is correctly called cold, since it does not readily heat and run into fermentation. Mixed with other manures, however, or well diffused through the soil, it aids materially in promoting vegetation. The horse being fed generally on less liquid food, and discharging less urine, yields a hotter and richer dung, which is admirably fitted for bringing substances into a state of fermentation, but answers best for the land when mixed with other varieties of manure. The dung of the pig is soft and *cold* like that of the cow, containing, like it, at least 75 per cent of water. As this animal lives on more varied food than any other which is reared for the use of man, the manure obtained from it is also very variable in quality. Applied alone, as a manure to roots, it is said to give them an unpleasant taste, and to injure the flavour even of the tobacco plant. It answers well for hemp and for hops; but when mixed with other manures, it may be applied to any crop. In some districts pigs' dung is considered one of the richest and most valuable that can be applied to the land. But the most generally useful manure is obtained by mixing all these varieties together, as is usually done in the manure-heaps of our larger farmers.

SECTION II.—DROPPINGS OF BIRDS. PIGEONS' DUNG AND GUANO. AFRICAN AND AMERICAN VARIETIES—THEIR COMPOSITION AND FERTILISING EFFECTS.

1. *Pigeons' dung.*—The dung of nearly all birds is distinguished by eminent fertilising properties. Some varie-

ties are stronger than others, or more immediate in their action, and all are improved for the use of the farmer by being some time kept, either alone or in compost. In Flanders the manure of one hundred pigeons is considered to be worth 20s. a-year for agricultural purposes. In Catalonia, Arragon, and some other parts of Spain, pigeons' dung is sold as high as 4d. a pound, for applying, when mixed with water, to flower-roots, melons, tomatos, and other plants.*

The dung of birds possesses the united virtues of both the liquid and solid excretions of other animals. It contains every part of the food of the bird, with the exception of what is absolutely necessary for the support and for the right discharge of the functions of its own body. It is thus fitted to return to the plant a greater number of those substances on which plants live, than either the solid or the fluid excrements of other animals; in other words, to be more propitious to vegetable growth.

2. *Guano* is the name given by the natives of Peru to the dung of sea-fowl, which in former periods used to be deposited in vast quantities on the rocky shores and isles of the Peruvian coast. The numerous shipping of modern times has disturbed and driven away many of the sea-fowl, so that much less of their recent droppings is now preserved or collected. Ancient heaps of it, however, mixed with feathers and fragments of bone, still exist in many places, more or less covered up with drifted sand, and also more or less decomposed. These are now largely

* The estimation in which it was held in ancient Palestine may be inferred from the statement, that, during a siege of Samaria, the fourth part of a cab of doves' dung was sold for 5 pieces of silver.—2 Kings, vi. 25. I may state, however, that what is here translated *doves' dung*, was considered by Linnæus to mean the bulbous root of the *Ornithogallum umbellatum*, still eaten in Palestine, and forming part of the food of some of the tribes of Hottentots at the Cape of Good Hope.

excavated, especially on the Chincha islands, for exportation, not only to different parts of the coast of Peru,—as seems to have been the case from the most remote periods,—but also to Europe, and especially to England. It is at present sold in this country at a price which varies from £8 to £11 a ton.

Guano was also imported, for a few years, (1843 to 1847,) in large quantities from the island of Ichaboe, and from other places on the west coast of Africa. The quality of the African was not equal, however, to that of the guano brought from Peru. It contained more water, and was in a more advanced stage of decomposition. The known sources of supply from this quarter are now nearly exhausted; and with the exception perhaps of a little from Saldanha Bay, there is none of it now in the market. Its price varied with the quality, from £3 to £8 a ton.

Guano is capable of entirely replacing farmyard dung,—that is to say, turnips and potatoes may be manured successfully with guano alone. It may be used either as a top-dressing to the young corn and grass; or it may be put in with the turnip-seed, or with the potato cuttings, being previously mixed with a quantity of fine dry soil, charcoal powder, or gypsum. It may also be mixed with water, and used as a liquid manure. It is applied in various proportions, from one to three, four, or five hundred weights per acre. Three cwt. of guano, without other manure, gave Mr Fleming of Barochan 18½ tons of potatoes per acre; and 5 cwt., with 20 bushels of wood ashes, gave him 32 tons of yellow turnips.

The application of guano to the sugar cane has largely increased the produce of sugar, both in the British West India Islands and in the Mauritius.

When applied in too large a quantity, the effect both upon the turnip and upon the after corn-crop is of a very hurtful kind. This is very strikingly shown by the following results of an experiment made in Ross-shire (in 1843 and 1844) with 4, 8, and 16 cwt. respectively to the Scotch acre :—

Quantity of Guano.	Effect on the Turnip Crop.	On the after crop of Wheat.
4 cwt.	Good turnips, 18 tons.	Good Wheat.
8 ...	Very indifferent 14 tons.	Inferior.
16 ...	Grew up wonderfully, looked beautiful, but there was *little bulb*. Produce 10 tons.	Stubble black, grain dark, and not larger than small rice.

3. *The fertilising effects of guano* depend mainly upon the quantity of ammonia which already exists in it, or which may be formed in it by its further decomposition, and upon the proportion of phosphates which are present in it. Of these the former is the more valuable ingredient of the two—that is to say, it would cost the farmer most money to buy it in a separate state, at its present price. The phosphates, in like manner, would cost more to buy in the shape of bones or of sugar-refiners' refuse, (animal charcoal,) than any of the other ingredients which the guano contains—the ammoniacal matter excepted.

4. *Composition.*—The following table exhibits the composition of four samples of guano, two from the South American and two from the African coast. These analyses do not enter much into details, but they are sufficient for ordinary purposes—as guides, that is, to the practical man.

	South American.		African.	
	Peruvian.	Bolivian.	Ichaboe.	Saldanha Bay.
Water,	13.09	6.91	16.71	18.35
Organic matter containing ammonia,	53.17	55.52	46.61	22.14
Common salt and sulphate of soda,	4.63	6.31	12.92	5.78
Carbonate of lime,	4.18	3.87	0.27	1.49
Phosphates of lime and magnesia,	23.54	25.68	22.40	50.22
Silicious matter or sand,	1.39	1.71	0.52	2.02
	100.	100.	99.43	100.

These analyses are not to be considered as doing more than *generally representing* the difference between the African and American guanos. The several cargoes, both of African and of American, which used to arrive in this country, differed much among themselves. As I have already stated, the importation of African guano has now almost entirely ceased.

It is one of the valuable qualities of guano, that it contains a mixture of so many of those substances on which plants live. The only ingredient in which it is manifestly defective is potash—of which it usually contains less than 1 per cent; and hence an admixture of wood ashes, and especially of *leached* or washed wood ashes, would be likely to improve its action upon the crops, in such soils as do not naturally abound in potash.

5. *Lobos Islands guano,* which is at this moment attracting so much of the attention of politicians, is said to be the produce of the seal or sea-wolf, and to be from 25 to 33 per cent less valuable than the guano of the Chincha islands.

6. *British guano.*—The successful employment of foreign guano has caused the droppings of pigeons, sea-fowls, and bats, to be sought for in the caves along our east and west coasts, and in our western islands. I have examined several samples from both coasts; but though they may prove valuable manures in the immediate neighbourhood where they are found, they are not rich enough to pay the cost of collection and transport to any considerable distance.

7. *Is guano permanent in its action?*—This is a question which the practical man naturally asks when he is about to employ it to a large extent. Experience seems to show that its beneficial action extends to at least two crops, when it is applied in proper quantity. Theory also indicates, that though the action of the ammoniacal salts may be more or less exhausted in a single season, yet that the effect of the phosphates and other saline substances it contains—which is very important—will continue beyond one year. But the kind and quality of the guano will materially affect the length of its action.

In general, however, it may be said, that as guano resembles bones very much in its composition, and as bones are known to benefit the crops in an entire rotation, so ought guano also. The chief difference between bones and guano is this—that the guano contains ammonia ready formed, or forming, so to speak—while the bones contain gelatine, which forms ammonia only after it has fermented. The ammoniacal part of the one, therefore, will act early, of the other after a longer period—while the permanent effects of the remaining ingredients of both will be very much alike if they are laid on in nearly the same proportions.

SECTION III.—ADULTERATIONS OF GUANO — HOW TO SELECT A SAMPLE OF GOOD QUALITY — NATIONAL VALUE OF THIS MANURE.

1. *Adulterations of guano.*—In consequence of the high price of guano, the great demand for it, and the ease with which the unwary farmer may be imposed upon, guano is adulterated with various substances, and to a great extent. Impositions even have been practised by selling as genuine guano artificial mixtures, made to look so like guano that the practical man in remote districts is unable to detect it. A sample of such pretended guano, which had been sold in the neighbourhood of Wigtown, and had been found to produce no effect upon the crops, when examined in my laboratory, was found to contain, in the state in which it was sold, more than half its weight of gypsum—the rest being peat or coal ashes, with a little common salt, sulphate of ammonia, and either dried urine or the refuse of the glue manufactories, to give it a smell. I could not satisfy myself that it contained a particle of real guano. Burnt earth and brick-dust are now prepared of various shades, and in fine powder, in special manufactories, for the purpose of mixing with guano and with artificial manures. These facts show how important it is that the farmer should possess some means of readily, and at a cheap rate, testing the costly manures he employs.*

* "Four vessels recently sailed hence for guano stations ballasted with gypsum, or plaster of Paris. This substance is intended for admixture with guano; and will enable the parties to deliver from the vessel a nice-looking and light-coloured article. Parties purchasing guano are very desirous of having it delivered from the vessel, as they believe they obtain it pure. The favourite material for the adulteration of

2. *In selecting a good guano,* the following simple observations will aid the practical man.

a. The drier the better—there is less water to pay for and to transport.

b. The lighter the colour, the better also. It is the less completely decomposed.

c. If it has not a strong ammoniacal smell, it ought to give off such a smell when a spoonful of it is mixed with a spoonful of slaked lime in a wine glass.

d. When put into a tumbler with water, stirred well about, and the water and fine matter poured off, it ought to leave little sand or stones.

e. When heated to redness in the air till all the animal matter is burned away, the ash should nearly all dissolve in dilute muriatic acid. The insoluble matter is useless sand or earthy adulterations.

f. In looking at the numbers in a published analysis of a Peruvian guano, those representing the water should be small; the organic matter containing ammonia should approach to 50 or 60 per cent; the phosphates should not much exceed 20 per cent; and the common salt and sulphate of soda ought not to form much more than 5 or 6 per cent of the weight of the guano. In Saldanha Bay guano the proportion of phosphates was much greater, and of organic matter less.

3. *The national value* of guano, and the consequent importance of preventing adulteration as far as possible, may be judged of from three important facts.

a. From the amount of the importation of it into this

guano, at the present moment, is umber, which is brought from Anglesea in large quantities. The rate of admixture, we are informed, is about 15 cwt. of umber to about 5 cwt. of Peruvian guano, from which an excellent-looking article, called African guano, is manufactured."—*Liverpool paper.*

country, which, during the last ten years, has been as follows:—

Years.	Tons.	Years.	Tons.
1841, . .	2,881	1847, . .	82,000
1842, . .	20,398	1848, . .	71,414
1843, . .	3,002	1849, . .	83,438
1844, . .	104,351	1850, . .	116,925
1845, . .	283,300	1851, . .	245,016
1846, . .	89,203		

b. That the quantity imported in 1851 would sell for upwards of two millions sterling, and with good management ought to produce two or three times its own value in grain or other vegetable food. In other words, such a yearly supply of guano is equal to the importation of foreign grain and other produce to the value of from four to six millions sterling.

c. It also serves as a stimulus, while it supplies one of the requisites, to the general introduction of improved methods of agricultural practice.

CHAPTER XVI.

Relative theoretical values of different animal manures.—Chemical distinction or difference between animal and vegetable manures.—Cause of this difference.—Effects of respiration.—Coldness of the droppings of the cow, and poorness of the manure from growing stock.—Improvement of the land by eating off with sheep.

SECTION I.—OF THE RELATIVE THEORETICAL VALUES OF THE DIFFERENT ANIMAL MANURES.

THE fertilising power of animal manures, in general, is dependent, like that of the soil itself, upon the happy admixture they contain of a great number of those substances which are required by all plants in the universal vegetation of the globe. Nothing they contain, therefore, is without its share of influence upon their general effects; yet the amount of nitrogen present in each affords one of the readiest and most simple tests by which their relative agricultural values, compared with those of vegetable matters, and with each other, can be pretty nearly estimated.

In reference to their relative quantities of nitrogen, therefore, they have been arranged in the following order—the number opposite to each representing the weight in pounds, which is equivalent to, or would produce the same sensible effect upon the soil as 100 lb. of farmyard manure:—

Farmyard manure, ...	100
Solid excrements of the cow, ...	125
———————— horse, ...	73

Liquid excrements of the cow,	91
——— horse,	16
Mixed excrements of the cow,	98
——— horse,	54
——— sheep,	36
——— pig,	64
Dry flesh,	3
Pigeons' dung,	5
Flemish liquid manure,	200
Liquid blood,	15
Dry blood,	4
Feathers,	3
Cow hair,	3
Horn shavings,	3
Dry woollen rags,	2½

It is probable that the numbers in this table do not err very widely from the true relative values of these different manures, in so far as the *organic* matter they severally contain is concerned. The reader will bear in mind, however—

1. That the most powerful substances in this table, woollen rags for example—2½ lb. of which are equal in virtue to 100 lb. of farmyard manure—may yet show less *immediate* and sensible effect upon the crop than an equal weight of sheep's dung, or even of urine. Such dry substances, as I have said, are long in dissolving and decomposing, and continue to evolve fertilising matter, after the softer and more fluid manures have spent their force. Thus, while farmyard manure or rape-dust will immediately hasten the growth of turnips, woollen rags will come into operation at a later period, and will prolong their growth into the autumn.

2. That besides their general relative value, as represented in the above table, each of these substances has a further special value not here exhibited, dependent upon the kind and quantity of the saline and other inorganic matters which they severally contain. Thus three of dry flesh are equal to five of pigeons' dung, in so far as the *organic* part is concerned; but the latter contains also a

considerable quantity of bone earth and of saline matter which is present only in minute quantity in the former. Hence pigeons' dung will benefit vegetation in circumstances where dry flesh would in some degree fail. So the liquid excretions contain much important saline matter not present in the solid excretions—not present either in such substances as horn, wool, and hair—and, therefore, each must be capable of exercising an influence upon vegetation peculiar to itself.

Hence the practical farmer sees the reason why no one *simple* manure, such as hair or flesh, can long answer on the same land; and why, in all ages and countries, the habit of employing *mixed* manures and artificial composts has been universally diffused. When mixed manures are not employed, the kind of manure which has been used must, after a time, be changed. A species of *rotation* of manures must, in fact, be introduced, in order that a second or third species of manure may give to the land those substances with which the first was unable to supply it.

SECTION II.—CHEMICAL DISTINCTION OR DIFFERENCE BETWEEN ANIMAL AND VEGETABLE MANURES.

In what do animal manures differ from vegetable manures? What is the cause of this difference? How does the digestion of vegetable matter improve its value as a manure?

1. The *characteristic distinction* between animal and vegetable manures is this—that the former contain a much larger proportion of nitrogen than the latter. This will be seen at once, by comparing together the tables given in the preceding pages, (205 and 238,) in which the numbers given represent the relative agricultu-

ral values of different vegetable and animal substances compared with that of farmyard manure. The lowest numbers represent the highest value, and the largest amount of nitrogen, and these low numbers are always opposite to the purest animal substances.

2. In consequence of their containing so much nitrogen, animal substances are further distinguished by the rapidity with which, when moist, they putrefy or run to decay. During this decay, the nitrogen they contain gradually assumes the form of ammonia, which is perceptible by its smell, and which, when proper precautions are not taken, is apt, in great part, to escape into the air. Hence the loss which occurs when manure is fermented too completely, or without proper precautions to prevent the escape of volatile substances. And as animal manure, when thus over-fermented, or permitted to give off its ammonia into the air, is found to be less active upon vegetation than before, it is reasonably concluded that to this ammonia, and the compounds formed along with it, or to the substances from which they are produced, the *peculiar* virtue of animal manures, when rightly prepared, is in a great measure to be ascribed.

Vegetable substances *in general* do not decay so rapidly, and emit little odour of ammonia when fermenting. When prepared in the most careful way, also, vegetable manure does not exhibit the same immediate and remarkable action upon vegetable growth as is displayed by almost every substance of animal origin. There are exceptions, indeed, to this general rule, since the crushed seeds of plants—rape-dust for example—produce an effect on many crops little inferior to that of animal manures. They, in fact, resemble animal substances very closely in their chemical composition.

SECTION III.—CAUSE OF THE DIFFERENCE BETWEEN ANIMAL AND VEGETABLE MANURES. EFFECTS OF RESPIRATION.

Whence do animal substances derive all this nitrogen? Animals live only upon vegetable productions containing little nitrogen; can they then procure all they require from this source alone? Again, does the act of digestion produce any chemical alteration upon the food of animals so as to render their excretions a better manure, richer in nitrogen than the substances on which they feed? Does theory throw any light upon the opinion generally entertained among practical men upon this point?

These two apparently distinct questions will be explained by a brief reference to one common natural principle.

1. Animals have two necessary vital functions to perform—to breathe and to digest. Both are of equal importance to the health and general welfare of the animal. The digester (the stomach) receives the food, melts it down, extracts from it those substances which are best suited to supply the wants of the body, and sends them forward into the blood. The breathers (the lungs) sift the blood thus mixed up with the newly-digested food, combine oxygen with it, and extract carbon—which carbon, in the form of carbonic acid, they discharge by the mouth and nostrils into the air.

Such is a general description of these two great processes; their effect upon the food that remains in the body, and has to be rejected from it, is not difficult to perceive.

Suppose an animal to be full grown. Take a full-

grown man. All that he eats as food is intended merely to renovate or replenish his system, to restore that which is daily removed from every part of his body by natural causes. *In the full-grown state, everything that enters the body must come out of the body* in one form or another. The first part of the food that escapes is that portion of its carbon that passes off from the lungs during respiration. This portion varies in weight in different individuals—chiefly according to the quantity of exercise they take. From 5 to 9 ounces a-day is the average quantity given off from the lungs of a full-grown man, though in periods of violent bodily exertion, 13 to 15 ounces of carbon are breathed out in the form of carbonic acid.

Suppose a full-grown man to eat a pound and a half of bread, and a pound of beef in 24 hours, and that he gives off by respiration 8 ounces of carbon (3500 grains) during the same time. Then he has

	Carbon.	Nitrogen.
Taken in his food, about	4500 grains, and	500 grains, while
He has given off in respiration, . .	3500 and little or no nitrogen.	
Leaving to be converted into his own substance, or to be rejected, .	1000 grains and	500 grains.

Our two conclusions, therefore, are clear. The vegetable food, by respiration, is freed from a large portion of its carbon, which is discharged into the air, while nearly the whole of the nitrogen remains behind. In the food consumed, the carbon was to the nitrogen as 9 to 1; in that which remains in the body after respiration has done its work, the carbon is to the nitrogen in the proportion of only 2 to 1.

It is out of this residue, *rich* in nitrogen, that the several parts of animal bodies are built up. Hence the

reason why they can be formed from food poor in nitrogen, and yet be themselves rich in the same element.

It is this same residue also which, after it has performed its functions within the body, is discharged again in the form of solid and liquid excretions. Hence the greater richness in nitrogen—in other words, the greater fertilising power possessed by the dung of animals than by the food on which they live.

2. It must also be borne in mind, that the digested food contains all the saline matter, as well as nearly all the nitrogen, which had entered the stomach of the animal. Weight for weight, therefore, the dung must be richer also in saline matter than the vegetable food, and therefore must be more fertilising in its effects upon the land. In an experiment made on the food and dung of the horse, it was found that while in the dry food the carbon was to the saline matter as 6 to 1, it was in the dry dung only as 2 to 1.

3. Two other remarks I may here add, because of their interest to the practical man.

a. The manure of the cow, taking it mixed, is not so rich in nitrogen as that of man. It is true that the cow, owing to its larger bulk and larger lungs, gives off perhaps eight or nine times as much carbon by respiration as an active full-grown man. But the weight of its daily food still farther exceeds that of a healthy man. Suppose the daily food of a cow to weigh ten times as much as the food we have supposed a man to eat, and to contain carbon and nitrogen in nearly the same proportions—and that it gives off 60 ounces of carbon each day from its lungs—then we have

	Carbon.	Nitrogen.
In the food, . .	45,000 grains.	5000 grains.
Given off by the lungs,	26,000 „	... „
To be ultimately rejected,	19,000 „	5000 „

In the mixed manure rejected by such a cow, therefore, the carbon would be to the nitrogen in the proportion of about 4 to 1; while in nightsoil it was, according to our former supposition, as 2 to 1. Thus the mixed dung and urine of the cow is less rich as an *immediately acting* manure than the mixed nightsoil and urine of man. And since much of the nitrogen, as well as of the saline matter of the food, is contained in the urine of the cow, if this urine be allowed to escape, the solid cow-dung will be still colder and less fertilising. The dry mixed manure of the cow is richer in nitrogen than the dry food, weight for weight, but not so much so as if the cow gave off from her lungs a larger proportion of the carbon contained in her food.

b. Since the parts of animals — their blood, muscles, tendons, and the gelatinous portion of their bones—contain much nitrogen, young beasts which are growing must appropriate to their own use, and work up into flesh and bone, a portion of the nitrogen contained in the *non-respired* part of their food. But the more they thus appropriate, the less will pass off into the fold-yard; and hence it is natural to suppose that the manure, either liquid or solid, which is prepared where many growing cattle are fed, the food being the same, will not be so rich as that which is yielded by full-grown animals. This deterioration has actually been observed in practice, and it may with some degree of certainty be expected in all cases to take place, unless, by giving a richer food to the young cattle, the difference to the farmyard is made up.*

* Though I have dwelt as long upon these interesting, and, I believe, novel considerations, as the limits of this little work will permit, yet for fuller details, and for perhaps a clearer exposition of the principles above advanced, I must refer the reader to my *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 828.

SECTION IV.—IMPROVEMENT OF THE LAND BY EATING OFF WITH SHEEP.

The eating off with sheep is a practice on which some light is thrown by the considerations presented in the preceding section. This practice is adopted in different places with a view to very different objects.

1. On sandy soils, as in Norfolk, the whole or part of the turnip crop is eaten off with sheep, for the purpose chiefly of treading down and consolidating the soil, and thus fitting it for the better growth of the succeeding crop of barley. The production of a mechanical effect upon the soil is here the chief thing sought for.

2. When the soil is not so light, the turnips are often eaten off with sheep for the sake of the regular and even manuring which the land is sure to obtain. The effect sought for here is also chiefly mechanical. The turnips could be drawn, and the dung collected, but it would afterwards have to be spread—and it could not by hand be so easily spread, or laid on the land so completely without loss.

3. Independent of the above considerations, the general benefit to the land of eating off with sheep arises from the conversion of the vegetable produce into a manure richer, weight for weight, in nitrogen and saline matter, and, therefore, having a more immediate and powerful effect upon the after crops. In the case of land which is otherwise in good heart or condition, perhaps no better or more profitable husbandry than this, for rural districts, could readily be recommended.

4. But the manure is richer, as we have seen, because the respiration of the animal separates a large proportion of the carbon which the food contains. This fact throws

light upon a question which the improving farmer has frequently asked himself in reference to poor or worn-out arable land, or to land he wishes to reclaim. If I sow a green crop—rape, or buckwheat, or rye, or tares—had I better eat it off with sheep, or plough it in? I am in doubt about the effect of ploughing in, but I am sure that by eating off I shall give the land a good manuring.

Now theory answers this question distinctly. If the *only object* be to enrich the ground, plough in green. By this means the carbon is saved which would otherwise be dissipated by the lungs of the animal,—and this carbonaceous matter is of great value in improving poor, thin, or sandy soils, in which organic matter is deficient.

But if enriching the soil be not the sole object—if some mutton also be desired—then it is good husbandry to eat off, with *full-grown and fattening stock*. The land will improve less rapidly in this way than by ploughing in, and it will be longer before you can safely crop it with corn, but it *will* gradually improve under such treatment.

Why fattening and not growing stock is to be kept on such land will appear from the considerations to be presented in the concluding chapter—*on the feeding of animals.*

CHAPTER XVII.

Saline and mineral manures.—The salts of ammonia as manures.—Ammoniacal liquor, sal-ammoniac, and sulphate of ammonia.—Results of experiments with these salts.—Quantity of nitrogen required by the wheat crop.—Carbonates, nitrates, and silicates of potash and soda.—Sulphates of potash and soda.—Common salt.—Sulphate of magnesia.—Sulphate of iron.—Gypsum.—Use of the phosphate and super-phosphate of lime, and cause of their beneficial action.—Use of kelp, and of the ashes of wood, straw, the husk of oats, barley, and rye, and of the sugar-cane.—Composition and use of peat or Dutch ashes.—Coal ashes.

THE general nature and mode of operation of such saline and mineral substances as are capable of acting as manures, will be in some measure understood from what has already been stated as to the necessity of nitrogen and of inorganic food to living plants, and as to the kind of inorganic food which they especially require. It will be necessary, however, to advert briefly to the more important of these manures,—their use, their mode of action, and the theory of their observed effects.

SECTION I.—THE SALTS OF AMMONIA AS MANURES.

The value of ammonia as a manure has been already spoken of (pages 28 and 56.) It exists in all fermenting animal manures, and thus is constantly applied to the land even in the least advanced districts. There are several states, however, in which it has lately begun to be used, unmixed with other substances, and with manifest advantage to the crops.

1. *Ammoniacal Liquor.*—This is water rich in am-

monia, which is distilled from coal during the manufacture of coal gas. It is of various degrees of strength, and therefore, if applied to the land alone, it must be diluted with a variable proportion of water. It often contains ammonia enough to yield, when saturated with spirit of salt, as much as a pound and a half of sal-ammoniac from a single gallon. That of the London gas-works is said to yield, when saturated with sulphuric acid, about 14 ounces of sulphate of ammonia from the gallon.

To grass land this ammoniacal liquor may be applied with great advantage, by means of a water-cart—being previously diluted with from three to five times its bulk of water. If too strong it will burn up the grass at first, especially if the weather be dry; but, on the return of rain, the herbage will again spring up with increased luxuriance.

On arable land it may be applied with profit to the young wheat or other corn by the water-cart, or it may be dried up by any porous material, and thus put into the turnip or potato drills. A friend in Northamptonshire writes me that 200 gallons of ammoniacal liquor per imperial acre, *drunk up* by sawdust and put into the drills, has alone given him an excellent crop of turnips. This manuring, however, cannot be expected to keep the land in heart. A certain proportion of bone-dust should be mixed with this ammoniated sawdust, or else the corn crops should afterwards be top-dressed with rape-dust, guano, or bones. If, indeed, the land be already *bone-sick*, the saturated sawdust may be used alone, or with a mixture of wood or peat ashes for one rotation.

The ammoniacal liquor may also be used advantageously to promote the fermentation of peat, sawdust, and other composts,—or it may be added to the ordinary dunghill, or to the liquid manure of the farmyard, and applied along with it to the land.

It is said to extirpate moss from old grass land more permanently than lime.

2. *Carbonate of ammonia* is the common smelling salts of the shops. It exists in the ammoniacal liquor above described, and is very useful, in a diluted state, in promoting vegetation. It is too expensive, however, in the form in which it is at present sold, to be of much use to the practical farmer. An ounce of it, dissolved in a gallon of water, gives a solution which destroys insects on rose-trees and other plants, and adds to their luxuriance at the same time. A few pieces laid on a plate and allowed to evaporate slowly into the atmosphere of a conservatory, are said to add greatly to the green and healthy appearance of the plants.

3. *Sal-ammoniac.*—The same may be said of muriate of ammonia, the sal-ammoniac of the shops. Though experiment has shown that this substance exercises a very beneficial influence on the growth of our cultivated crops, yet the pure salt is too high in price to admit of its being economically used in ordinary husbandry. An impure variety, however, is prepared from gas liquor, which is sold at about 15s. a cwt.

4. *Sulphate of ammonia* is now manufactured at a comparatively cheap rate, and is sold at £16 a ton. This salt may be applied with advantage, especially to soils which are locally called *deaf*—which contain, that is, much inert vegetable matter, and to such as are naturally rich in phosphates. It may also be mixed with bones, rape-dust or wood-ashes, and put into the turnip or potato drills, or it may be used as a top-dressing in spring to sickly crops of corn.

A case is mentioned of a field being manured for wheat, in part with ordinary farmyard manure, and in part with 1½ cwt. per imperial acre (cost £1, 2s.) of sulphate of ammonia—when the produce of the former was

24, and of the latter 33 bushels per imperial acre. In other cases, also, it has been found a profitable application, both to young corn and to meadow hay.

Faded flowers, when introduced into a solution of sulphate of ammonia, are said to be perfectly restored and revivified.

5. *Steeping of seeds in the salts of ammonia.*—The salts of ammonia, especially sal-ammoniac and the sulphate of ammonia, have been strongly recommended as steeps for seed-corn. They have in many cases been found very advantageous in hastening germination, and in increasing the after luxuriance of the crop. Thus, in one experiment, seeds of wheat, steeped in the sulphate of ammonia on the 5th of July, had by the 10th of August tillered into nine, ten, and eleven stems of nearly equal vigour, while unprepared seed had not tillered into more than two, three, or four stems.

Sal-ammoniac has a similar effect. In Upper India it is prepared by heating together camel's dung and sea salt, and is used in the plains, among other purposes, for the steeping of seeds.

It is to be observed, however, that neither when applied directly as a manure to the growing crops, nor when used as a steep for the seed, can the salts of ammonia alone bring a plant to maturity. They tend to hasten its growth, *if all its other wants can be readily supplied by the soil;* but if this is not the case, a quick decay will succeed to a short-lived luxuriance.

SECTION II.—RESULTS OF EXPERIMENTS WITH THE SALTS OF AMMONIA. NITROGEN NECESSARY TO THE WHEAT CROP.

The last mentioned fact, as well as the general value of the salts of ammonia, is illustrated by the results of

some experiments made by Mr Lawes at Rothampstead in Hertfordshire. He sowed wheat for three successive years on the same piece of ground, applying only mineral manures the first year, and only ammoniacal manures the second and third years. The following were the results:—

	Application per imperial acre.		Produce. Grain.	Straw.
1844.	Superphosphate of lime,	560 lb.	16 bush.	1112 lb.
	Silicate of potash, .	220		
1845.	Sulphate of ammonia, } each	1½ cwt.	31½ ...	4266 ...
	Muriate of do.			
1846.	Sulphate of ammonia,	2 ...	27 ...	2244 ...

Thus, upon a soil already rich in mineral manure, the application of salts of ammonia nearly doubled the crop of grain in 1845, and quadrupled that of straw; and, in 1846, added again one-half to the grain above 1844, and doubled the straw. In each case, however, some allowance must probably be made for the influence of natural varieties in the seasons.

As to the necessity of nitrogen to the wheat crop, Mr Lawes concludes, from numerous experiments, that, *upon his soil and in his locality*, five pounds of ammonia—or four of nitrogen, in some other available form—are "required for the production of every bushel of wheat beyond the natural yield of the soil and season." * But as a bushel of wheat contains only about 1 lb. of nitrogen, (equal to 1¼ lb. of ammonia,) it is obvious that, if this estimate be correct, the greater part of the nitrogen is lost to the farmer. The subject, therefore, is open to further investigation.

* *Journal of Royal Agricultural Society of England*, viii. 246.

SECTION III.—SALTS OF POTASH, SODA, MAGNESIA, AND IRON.

1°. *Carbonates of potash and soda.*—The common pearl-ash, and the common soda of the shops, have not in this state been much employed in agriculture. Both, however, greatly promote the growth of strawberries in the garden,—and the latter is now cheap enough (10s. a cwt.) to admit of its being tried as a top-dressing on clovers and grass lands, on such as are old and mossy especially, with every prospect of advantage. It should be dissolved in much water, and put on with a water-cart, or thoroughly mixed with earth, and applied as a top-dressing. Mixed at the rate of one cwt. an acre, with bone or rape dust, or even with guano, it may be expected to improve both the turnip and the potato crops.

Carbonate of soda, in the form of *soda ash*, has been applied with success to kill or to remove the effects of the wire-worm. It may either be sown with the wheat in winter, or applied, as a top-dressing in the spring, to the affected wheat or oats.

2°. *Nitrates of potash and soda.*—Saltpetre and nitrate of soda have been deservedly commended for their beneficial action, especially upon *young* vegetation. They are distinguished, like the salts of ammonia, for imparting to the leaves a beautiful dark green colour, and are applied with advantage to grass and young corn of any kind, at the rate of 1 cwt. to 1½ cwt. per acre. They are said even to benefit young fir-trees. Applied to young sugar-canes they have been found largely to increase the crop, and even, in the second year after their application, to add much to the luxuriance of the cane fields. The

nitric acid they contain yields nitrogen to the plant, while potash and soda are also put within reach of its roots, and no doubt serve many beneficial purposes. Upon land rich in phosphates, nitrate of soda is a profitable application to wheat, being found, in Norfolk, to return an increase of from 4 to 7 bushels of grain for every cwt. applied to the corn in spring.* It is especially recommended for wheat, on light, gravelly, and sandy soils, and on cold undrained clays.

3°. *Sulphate of potash* is likely to be useful, especially to root and leguminous crops. Its price, however, is usually high, varying from £12 to £20 a ton.

4°. *Common salt* has, in many districts, a fertilising influence upon the soil. It destroys small weeds; improves the quality of pastures, and renders them more palatable; strengthens and brightens the straw, and makes the grain heavier per bushel, both of wheat and oats. It has been observed, also, to produce specially good effects upon mangold-wurtzel.

A small quantity of salt is absolutely necessary to the healthy growth of all our cultivated crops, but it is in inland and sheltered situations, and on high lands often washed by the rains, that its effect is likely to be most appreciable. The spray of the sea, borne to great distances by the winds, is in many districts, where prevailing sea winds are known, sufficient to supply an ample annual dressing of common salt to the land.†

It has sometimes been found to be of still more advantage, in strengthening the straw, to apply a mixture of quicklime with a fourth or a fifth part of its weight of

* See the Author's *Lectures on Agricultural Chemistry*, 2d edition, p. 595.

† At Penicuik, near Edinburgh, the rain that falls contains so much common salt as alone to convey 640 lb. to every acre in a year.—(Dr MADDEN.)

dry salt; or the salt may be dissolved in water, and the lime heap slaked with the solution—or sea water may be at once employed to slake the lime.

5°. *Sulphate of soda*, or Glauber's salt, has lately been recommended in this country for clovers, grasses, and green crops. Mixed with nitrate of soda it produces on some soils remarkable crops of potatoes, and in some localities, when used alone, it has greatly benefited the turnip crop. Mr Girdwood found that 1½ cwt. of this sulphate per acre, sprinkled upon the other manure in the drills, added 16 bushels an acre to his crop of beans. It is on rich land only, however, that the addition of a single saline substance can be expected to produce results so favourable as this.

6°. *Silicates of potash and soda.*—When potash and soda are melted together with silicious sand, they form a kind of glass which is soluble in water. This has produced remarkable effects upon the potato crop, and, like other silicates, is recommended as a strengthener of the straw of our corn crops.

7°. *Sulphate of magnesia*, or Epsom salts, is also beneficially applied in agriculture to clovers and corn crops. It can be had in pure crystals at 10s. a cwt., and in an impure state at from 3s. to 6s. a cwt. It has been found of advantage as a top-dressing for the young wheat, and as an application to the potato. Where the soil is deficient in magnesia, it may always be expected to improve the crops of corn.

8°. *Sulphate of iron.*—Common green vitriol, applied in the form of a weak solution, has been observed to strengthen feeble plants, and to give them a brighter green. It has also been used as a top-dressing for grass, and as an application to diseased fruit trees. It deserves a further trial.

SECTION IV.—USE OF THE SULPHATE AND PHOSPHATES OF LIME, AND CAUSE OF THEIR BENEFICIAL ACTION.

1°. *Sulphate of lime*, or gypsum, is in Germany applied to grass land with great success, and over large tracts of country. In the south of England it has been applied to some grass lands with benefit for thirty-five years in succession, at the rate of 2½ cwt. per acre. It supplies the lime and sulphuric acid annually, which are annually removed by the crop. In the United States it is used for every kind of crop; and I have there seen it produce very striking effects on Indian corn. It is especially adapted to the pea, the bean, and the clover crops. It is more sensibly efficacious when applied in the natural state than after it is burned.

The *sulphates* all afford sulphur to the growing plant, while the lime, soda, magnesia, &c., which they contain, are themselves in part directly appropriated by it, and in part employed in preparing other kinds of food, and in conveying them into the ascending sap.

Though there can be no question that these sulphates, and other similar substances, are really useful to vegetation, yet the intelligent reader will not be surprised to find, or to hear, that this or that mineral substance has not succeeded in benefiting the land in this or that district. If the builder has already bricks enough at hand, he needs mortar only, to enable him to go on with his work: so, if the soil contain gypsum or sulphate of magnesia in sufficient natural abundance, it is at once a needless and a foolish waste to attempt to improve the land by adding more; it is still more foolish to conclude, because of their failure in one spot, that these same

saline compounds are unlikely to reward the patient experimenter in other localities.

2°. *Phosphates of lime.* — *a. Burned bone.* — When bones are burned in an open fire, they diminish in weight about one-half, and leave behind a white earthy matter long known by the name of *bone earth.* This bone earth consists chiefly of *phosphate of lime* (page 214.)

Bones are known to be an excellent manure, and as our cultivated crops, and especially our corn crops, contain much phosphoric acid, it has been justly concluded that part of their effect is due to the bone earth they contain. Hence the use of burned bones as a manure has been warmly recommended.

In soils which are poor in phosphate of lime, there is no doubt but burned bones will be likely to benefit the crops of corn ; but there are few soils, I think, in which a ton of bone-dust would not produce a better effect than the ash left by an equal weight of bones.

b. Native phosphate of lime. — Phosphate of lime is found as a native mineral in many countries, and has been applied with advantage to the soil. It has lately been met with in the States of New York and New Jersey in sufficient quantity to make it likely to prove a profitable article of import into this country. It has also been discovered in considerable quantity in the marls of the crag and green-sand formations (see p. 103,) of England, and is now dug up in large quantities for agricultural purposes.* In our ordinary limestones it also exists in variable quantity. In a burned lime from Carluke, which is full of fossils, I have found it to the extent of $2\frac{1}{3}$ per cent; so that every ton of such lime conveys to the land as much phosphate of lime as two bushels of

* *Journal of the Royal Agricultural Society*, vol. ix. p. 56, and vol. xii. p. 93.

bones. This must modify in a favourable manner the effect of such lime when applied to the land.

c. Acid or *super-phosphate of lime.*—When burned bones are digested with sulphuric acid diluted with three times its bulk of water, gypsum (sulphate of lime) is produced, and falls to the bottom of the solution, while the phosphoric acid, and a portion of the lime, remain in the sour liquid above it. When this liquid is boiled down or evaporated to dryness, it leaves a white powder, which is known by the name of acid or super-phosphate of lime. Under the latter name it has been introduced into the manure market. It is extensively manufactured in this country, by grinding the mineral phosphate obtained from the *crag* of Norfolk and Suffolk, (p. 102,) mixing it with about an equal weight of strong sulphuric acid, and then drying the whole. Some manufacturers mix a portion of bone dust with the mineral powder, and thus produce a manure containing some animal matter, and therefore of more general utility.

As the ordinary burned bones are difficult to dissolve in the soil, and as the acid phosphate is more easy of solution, it is likely to be taken up more readily by the roots, and thus more rapidly to aid the growth of plants. These super-phosphates are sold at present at about £7 a ton.

Numerous experiments have been made with the super-phosphate, and very remarkable results have been obtained by its use, chiefly as a manure for the turnip crop, but also as a top-dressing for grass, and for wheat, and other kinds of corn. What is sold as super-phosphate by the manufacturers, is very variable in its composition, and is often largely adulterated.

SECTION V.—OF THE ASHES OF SEA-WEED, WOOD, STRAW, THE HUSK OF OATS, BARLEY, AND RICE, AND OF THE SUGAR CANE.

1. *Kelp* is the ash left by the burning of sea-weed. It contains potash, soda, lime, silica, sulphur, chlorine, iodine, and several other of the inorganic constituents of plants which are required by them for food. It is nearly the same also—with the exception of the organic matter which is burned away—with the sea-weed which produces such remarkably beneficial effects upon the soil. In the Western Isles a method is practised of half-burning or charring sea-weed, by which it is prevented from melting together, and is readily obtained in the form of a fine black powder. The use of this variety ought to combine the beneficial action of the ordinary saline constituents of kelp, in feeding or preparing food for the plant, with the remarkable properties observed in animal and vegetable charcoal. In Jersey, the sea-weed is dried and burned in the kitchen grates, and the ash is considered to be efficacious in destroying grubs. In the Orkneys, potatoes are raised by means of a mixture of peat ashes and kelp, applied at the rate of fifty bushels to the Scotch acre.

2. *Wood ash* contains, among other substances, a portion of common *pearl ash* in an impure form, mixed with sulphate and *silicate* of potash. These substances are all valuable in feeding and in preparing the food of plants, and hence the extensive use of wood ash as a manure in every country where it can readily be procured. Wood ash, applied alone, is especially beneficial to clovers, beans, and other leguminous plants. Mixed with bones in nearly equal bulk, it is extensively employed in this

country as a manure for turnips. In some soils it has been found, without any admixture, to raise large crops of potatoes. In Persia, seed wheat and melon seeds are always steeped, for 24 hours before sowing, in a ley of wood ashes. In Lower Canada, 40 bushels of wood ashes applied alone, give a crop of 200 to 250 bushels of potatoes.

3. *Lixiviated wood ash.*—When the common wood ash is washed with water as long as anything dissolves, and the solution is then boiled to dryness, the common potash of commerce is obtained. But a large portion of the ash remains behind undissolved, and in countries where much wood is burned for the manufacture of potash, this *lixiviated* or washed refuse accumulates. It consists of silicate of potash mixed with silicate, phosphate, and carbonate of lime, and when applied to the land is remarkably favourable to oats. It suits better for clay lands, and when laid on in considerable quantity, (1 or 2 tons to the acre,) its effects have been observed to continue for 15 or 20 years. (SPRENGEL.)

4. *Straw ashes.*—In this country straw is seldom burned for the ash. In Germany, rye-straw is not unfrequently burned, and the ash employed as a top-dressing. The dry straw is strewed over the field, then burned, and the ash ploughed in on the spot. In many countries—among others, in some parts of the United States—the straw is often burned, and the ash scattered to the wind. When it is too much trouble to ferment the straw in the farm-yard, labour might surely be spared to strew the ash upon the fields from which the crop was taken. The soil would not fail to give a grateful return.

5. *Ash of the husk of oats, barley, and rice.* — The husk, seeds, or shellings of oats or barley, being supposed to contain no nourishment, are often burned for the pur-

pose of heating the kiln on which the grain is dried. When thus burned, these husks leave a considerable quantity of a white or grey ash. The oat husk I find to leave about 5½ per cent of its weight. This ash has hitherto been neglected by the millers, being generally thrown into the stream by which their mills are worked. It should, however, be carefully preserved. It may be expected to prove a valuable top-dressing to meadow land, to young corn crops, and especially to bog oats. One miller in the north of Scotland informs me that he makes about two bushels a-day of ash from the husk of the oats he grinds. The waste of this ash, long persevered in, can scarcely have failed slowly to impoverish the adjoining land.

In China, India, and other countries where rice is grown, the husk of this grain also is burned; but the ash is rarely afterwards returned to the soil. In China, it is said to be employed in the making of certain articles of manufacture.

6. *Cane ash.*—The sugar-cane, when brought from the mill in the state of *trash*, is burned for the purpose of boiling down the syrup. The ash left by it is rich in those saline substances, without which the cane cannot thrive. Without having personally examined any of our West India plantations, I may safely hazard the opinion that some, at least, of the exhaustion complained of by the planters is owing to the neglect of this valuable ash—and that the large importation of foreign manures, now had recourse to, might by and by be in some measure dispensed with, by carefully collecting, grinding, and returning it to the soil.

SECTION VI.—COMPOSITION AND USE OF PEAT OR DUTCH ASHES.—COAL ASHES.

Peat or Dutch ashes are the ashes of peat burned for the purpose of being applied to the land. They vary in composition with the kind of peat from which they have been prepared. They often contain traces of potash and soda, and generally a quantity of gypsum and carbonate of lime, a trace of phosphate of lime, and much silicious matter. In almost every country where peat abounds, the value of peat ashes as a manure has been more or less generally recognised. The following analyses of two samples of such ashes from the Paisley moss, and of two from the island of Lewis, all examined in my laboratory, show how valuable, and, at the same time, how very different in quality, such ashes may be, even when they are obtained from the same locality.

a. Ashes from the Paisley moss.

	White Peat Ashes.	Black Peat Ashes.
Charcoal,	54.12	3.02
Sulphates and carbonates of potash, soda, and magnesia,	6.57	5.16
Alumina,	2.99	2.48
Oxide of iron,	4.61	18.66
Sulphate of lime,	10.49	21.23
Carbonate of ditto,	8.54	3.50
Phosphate of ditto,	0.90	0.40
Silicious matter,	10.88	43.91
	99.10	98.36

It will be observed that the first of these contained more than half its weight of unburned charcoal, and still was richer than the other, weight for weight, both in soluble salts and in phosphate of lime—two of their most valuable ingredients. The reason of this is, that the white peat, being nearer the surface, consists of vege-

table matter less decomposed. The ashes of the upper layers of peat, therefore, will generally be more valuable than those of the under layers.

b. Ashes from the island of Lewis.

Chloride of sodium, (common salt,)	0.41	0.29
Phosphate of lime, . . .	2.46	6.51
Sulphate of lime, (gypsum,) . .	28.66	16.85
Sulphate of magnesia, . .	1.68	2.01
Magnesia, } in state of silicate and carbonate,	6.32	5.86
Potash and soda, } in state of silicate and carbonate,	5.32	3.59
Alumina, . } in state of silicate and carbonate,	11.63	7.54
Oxide of iron, . . .	9.18	6.58
Silica, soluble in caustic potash, .	15.55	28.58
Insoluble silicious matter and sand, .	7.94	14.20
Carbonic acid, charcoal, and loss, .	10.85	7.99
	100.	100.

These samples, again, present other differences. They contain, in addition to the alkaline matter and the gypsum, a more considerable proportion of phosphate of lime than the others. In the one, the phosphate amounts to 6½ per cent, and must contribute materially to its fertilising value. The soluble silica is also deserving of notice, as likely to be useful—especially to grass land and to crops of corn.

Peat ashes are not unfrequently used alone, and with success, for the raising of turnips. Much of their success, however, will depend on the peculiar composition of the ashes employed.

In Lancashire, peat only half burned is considered preferable to double the quantity burned to a perfect ash.

Coal ashes consist in general of alumina and silica mixed with a variable proportion of gypsum, carbonate of lime, phosphate of lime, and oxide of iron, mixed with half-burned coal. They vary, however, with almost every different kind of coal that is burned.

CHAPTER XVIII.

Why saline manures are required by the soil. — Mode of determining their local value.—Circumstances necessary to insure the successful application of saline manures.—Of saline manures which exercise a special or specific action upon plants.—Results of experiments with mixed saline manures, made with the view of increasing the crop or of affecting its quality.—Artificial mixtures in imitation of valuable natural manures.—Recipe for artificial guano.

SECTION I.—WHY SALINE MANURES ARE REQUIRED BY THE SOIL.

THE use of saline substances as manures is of comparatively recent introduction. In many districts, however, they are indispensable, if we wish to maintain the present condition, or to restore the ancient fertility of the land. This will appear from the following considerations:

1. These saline substances exist in all plants, and must therefore abound, to a certain extent, in all soils in which plants can be made to grow.

2. The rains gradually wash out from the surface—especially of undrained arable soils, and in inland districts — a portion of the saline matter they contain. If the surface soil is to be retained in its present condition, this natural waste must, by some means or other, be supplied.

3. The crops we carry off the land remove also a portion of this saline matter from the soil, and thus gradually

impoverish it, if the saline substances be not again brought back.

4. And though we return to the soil, in the form of farmyard manure, all the straw of our corn crops and the dung of our cattle, the land still loses all that we carry to market, and all that escapes from our farmyards and dung-heaps in the form of liquid manure. Even where tanks for liquid manure are erected, the farmer can never return to the land *all* the saline substances contained naturally even in his straw. The rains that fall, were there no other cause of waste, would wash away some portion of what he would desire to carry back into his field.

The necessary waste of saline matter, arising from the above causes, must be supplied from some source or other. When, for a long period of time, the land has maintained its fertility without receiving any artificial supply, it must contain within itself naturally a very large proportion of these substances — must derive from springs a continued accession of such matter, or from waters that flow down from a higher level and bring with them the washings of the upper soils — or it must obtain from abundant sea-spray a sufficiency to supply the wants of the plants that grow upon it.

The practical man will readily acknowledge that, when a sufficiency of saline matter is not conveyed to his land from these or similar sources, he must necessarily supply it by art. He will understand, also, that the saline manures he adds to the soil operate by yielding to the plant what it could not otherwise so readily obtain ; and that a saline substance which has been found to benefit his neighbour's land, may happen, when applied, to do no good to his own—because his own may already contain a sufficient supply of that substance.

SECTION II.—MODE OF DETERMINING THE LOCAL VALUE OF SALINE MANURES.

In order, therefore, to determine whether *his* land will readily be benefited by the application of those saline substances from which, in other districts, or upon other soils, much benefit has been derived, the intelligent farmer will commence a series of preliminary trials or small experiments.

That many of the saline substances described in the preceding Sections may be *profitably* applied to most soils by the practical farmer, can no longer be doubted. At the same time, no prudent man will at once expend any large sum upon them, until either he himself, or some of his immediate neighbours who cultivate a similar soil, have previously proved their efficacy on a smaller scale. It is no doubt the duty of every practical farmer—a duty he owes not only to his country but to himself—to be alive to the benefits which are to be derived from every improved method of culture that may be introduced; but it is no less his duty to avoid every reasonable risk of pecuniary loss which might be injurious to himself.

Suppose, therefore, I were to enter upon a farm which I was desirous of rendering as productive as possible, by the application of every new manure, or every new method of culture that might prove to be suited to the kind of soil I possessed, I would begin by trying the effect of each manure or method upon a single acre, and I would extend my trials or alter my methods according to the success I met with.

Among saline manures, for example, I would try nitrate of soda, or carbonate of soda, or wood ashes, or sulphate of soda, or common salt, or silicate of soda, or gypsum, or

sulphated urine, or guano, or the ammoniacal salts, or the soluble phosphates, or a mixture of two or more of these substances, on a single acre or half acre of my various crops—*never expending in this way, during any one year, more than I could easily afford to lose if my trials should fail;* and I would not begin to use any of these substances largely till I was satisfied that there was a reasonable prospect of remuneration. And having once begun upon this assurance, I would cease applying them for a while as soon as the crops no longer gave me a fair return for my outlay—the probability then being, that the soil for the present had obtained enough of the peculiar substance I had been employing, and stood more in need of some other.

Thus if, as happened to a friend of mine, a dressing of salt was followed by a produce of 35 bushels from the first wheat crop, and yet, when applied to the next crop of the same grain on the same field, the yield was only 20 bushels, I should conclude that, for the present, my land was sufficiently salted, and that I had better apply something else. I would therefore begin my experiments anew upon my salted land. I would try some of the other substances above named, employing always the same caution and economy as before, and carefully keeping an account of my procedure, and of my profit and loss from each experiment.

Such facts, also, as that in the State of New York, after a long-continued use of gypsum, the employment of *leached* or exhausted wood ashes (p. 259) was found to be more beneficial, would incline me to make many trials of such variations or rotations of manures.

I should thus have always several experimental patches upon my farm; and I should not only avoid the risk of serious disappointment and pecuniary loss, but I should

enliven my ordinary farm routine by the interest I should necessarily feel in watching the results of my different experiments—I should gradually acquire habits of reflection, and of careful observation also, which would be of the greatest possible service to me in all my future operations.*

SECTION III.—OF THE CIRCUMSTANCES WHICH ARE NECESSARY TO INSURE THE SUCCESSFUL APPLICATION OF SALINE MANURES.

The application of saline substances to the soil is not always attended with sensible benefit to the crop. The same substance which, in one district, or in one season, has produced an increased return, may fail in another district or in a different season. The circumstances which are necessary to insure success in the application of saline manures are chiefly the following:—

1°. They must contain one or more of those substances which are necessary to the growth of the plant, and in a condition or state of combination in which the plant can take them up.

2°. The soil must be more or less deficient in these substances.

3°. The weather and soil must be moist enough to admit of their being readily dissolved and conveyed to the roots, or the land must be artificially irrigated.

4°. They must not be applied in too large a quantity, or allowed to come in contact with the young shoots in too concentrated a form. The water that reaches the roots or young leaves must never be too strongly impreg-

* For numerous suggestions as to such experiments, I would refer the reader to my published *Experimental Agriculture*—a work entirely devoted to the subject of rural experiments.

nated with the salt, or, if the weather be dry, the plant will be blighted or burned up.

5°. The soil must be sufficiently light to permit the salt easily to penetrate to the roots, and yet not so open as to allow it to be readily washed away by the rains. In reference to this point the nature of the subsoil is of much importance. A retentive subsoil will prevent the total escape of that which readily passes through a sandy or gravelly soil; while a very open subsoil, again, may retain little or nothing of what has once made its way through the surface.

6°. I may add, lastly, that it is in poor or worn-out soils that all such applications may be expected to produce the most marked and characteristic effects.

SECTION IV.—OF SALINE MANURES WHICH EXERCISE A SPECIAL OR SPECIFIC ACTION UPON PLANTS.

An interesting branch of the present part of our subject is the use of what are called special manures. Certain substances have been observed to exercise a special action,

1. *Upon all plants.*—Thus, the salts of ammonia promote the growth, or prolong the green and growing state, of most plants. Nitrate of soda has a similar effect—while the addition of lime to the soil, especially in well-drained and high lands, almost uniformly hastens the ripening of the seed, and produces an earlier harvest.

2. *On particular parts of plants;*—as when the gardener improves his roses by mixing manganese with the soil, reddens his ornamental hyacinths by putting carbonate of soda into the water in which they grow—or by other substances, as by the *acid* or *super*phosphate of soda, attempts to vary the hue or bloom of his cultivated

flowers. This principle is attended to in practical agriculture, when substances are mixed with the manure, which are believed to be specially required by the *stalk* of corn, where a field produces a defective straw—or by the *ear*, where the grain refuses to fill. The application of silicate of potash, of soda, or of lime, to the soil may add strength to the straw, while the phosphates fill the ear, or bring it to earlier maturity—as carbonate of potash, according to Wolff, promotes the growth of the leaves and stems of the vine, while the phosphates develop the fruit.

3. *On particular kinds of plants.*—Farmyard manure rarely comes amiss to any soil or any crop; but gypsum exercises a peculiar action upon red clover; while wood-ashes, lime, and other alkaline manures, cause white clover to spring up spontaneously, where it had before refused to grow even when sown. So lixiviated wood ashes are favourable to oats; ammonia, or the nitrates, are by some regarded as the peculiar manures for wheat; phosphate of magnesia has been extolled as a specific for potatoes; and superphosphate of lime for our British turnip crops.

All such facts as these are exceedingly valuable. Many of the alleged specifics, however, are only *locally* so. Thus bones, which produce such wonderful effects in Great Britain, especially upon turnips and upon some old grass lands, as those of Cheshire, are much less conspicuously effective in some parts of Germany, and even of our own island; * while gypsum, so much and so generally prized by the German and American farmer, is more rarely found to answer the expectations of the English agriculturist.

The truth is, that if the crop we wish to raise specially

* On some of the soils of the green-sand, for example.

requires any one substance which is not present in sufficient quantity in the soil, that substance will there prove a specific for that crop; while, in another soil in which it is already abundantly present, this substance will produce little beneficial effect. Failures, therefore, may every now and then be expected in the use of so-called *specific manures*, the evil of which is not limited to THE IMMEDIATE LOSS experienced by the incautious experimenter. They serve also to dishearten those who, through their much faith, have been disappointed in their expectations, and thus to retard the progress of a truly rational experimental agriculture.

SECTION V.—RESULTS OF EXPERIMENTS WITH MIXED SALINE MANURES, MADE WITH THE VIEW OF INCREASING THE QUANTITY OF THE CROP.

The same remark applies also to artificial *mixed* manures, when held forth as specifics for any or for all crops on every soil. The animal and vegetable manures which occur in nature, are all mixtures of a considerable number of different substances, organic and inorganic. We are imitating nature, therefore, and are in reality so far on the right road when we compound our artificial mixtures. The soil may be deficient in two, three, or more substances; and to render it fertile, it may be necessary to add all these; while, if it be defective in one only, we are more likely to administer the right one, if we add a mixture of several at the same time. It is *safer* and *surer*, therefore, to add a mixture of several saline substances to our soils.

There are only two ways, however, in which we can safely make up mixtures that are likely to be useful—either by actual experiment upon the kind of land we

wish to improve, or by an exact imitation of the procedure, and by attention to the requirements of nature.

1. *Mixture of nitrate with sulphate of soda.*—In 1840 I recommended the trial of sulphate of soda (Glauber's salts) as a manure, and in 1841, Mr Fleming of Barochan, besides making an experiment with the sulphate alone, tried a *mixture* of it with nitrate of soda in equal weights —adding 1½ cwt. of the mixture to the acre. The effect of this mixture as a *top-dressing* upon potatoes was extraordinary. *The stems were six and seven feet in length, and the produce upwards of* 30 *tons per imperial acre.* In 1842, tried on a larger scale, the produce was not so extraordinary; but, though a very dry season, the produce was 18 tons per acre of early American potatoes; while the dung alone, 40 cubic yards per acre, gave less than 13 tons. These results are sufficiently striking to justify the reader in trying this mixture on any soil. If his fields be like the land of Mr Fleming, the trial may prove eminently successful; if different in physical character or chemical composition, or if the season be unpropitious, the result may be less favourable. A mixture, though it succeed in the hands of fifty experimenters, will still not be entitled to be considered as a specific. It must first be found *never to fail.*

The cost of this mixture, as applied per acre, was at that time as follows:—

75 lb. nitrate of soda, at 22s. per cwt., . .	£0	14	9
75 lb. *dry* (uncrystallised) sulphate of soda, at 9s.,	0	6	3
	£1	1	0

The increased produce from this application — strewed about the young plants when they came above ground— was 8 *tons per acre* in 1841, and 5 *tons per acre* in 1842.

2. *The superior effect of mixtures* above that of the

substances they contain when employed singly, is shown in an interesting manner by the following results, obtained by the same experimenter :—

An entire field was manured for potatoes with 40 cubic yards of dung, and when the potatoes—early Americans—were a few inches above the ground, different measured portions of the field were top-dressed with different saline substances, with the following results per imperial acre :—

	Tons.
Dung alone gave	12¾
... with 2 cwt. sulphate of soda, . .	12¾
... ... 1½ cwt. nitrate of soda, . .	16
... ... 1¼ cwt. sulphate, ... ¾ cwt. nitrate, } mixed, .	18

Here, though the sulphate alone produced no increase, it materially augmented the effect of the nitrate when the two were applied together.

3. *Sulphate of soda with sulphate of ammonia.*—Again, on the same field on which sulphate of soda, applied alone, gave no increase,

	Tons.
1½ cwt. sulphate of ammonia alone gave only .	14½
While 1½ cwt. sulphate of soda, and ¾ cwt. sulphate of ammonia, } mixed, gave .	18¾

Being an increase of 6 tons an acre above sulphate of soda, and 4 tons above sulphate of ammonia applied alone.

4. *Nitrate of soda with sulphate of magnesia.*—Also on the same field, while

	Tons.
1½ cwt. of nitrate of soda gave, as above, only .	16
And 1½ cwt. of sulphate of magnesia, only . .	13¼
1 cwt. of each, mixed together, gave . .	22½

Thus experiment, as well as theory, indicates that *the application of several saline substances mixed together,*

is more likely to increase the produce of the soil than a larger addition of either applied alone.

5. *Phosphate of magnesia with phosphate of ammonia.* —I have said that attention to the requirements of nature will indicate what mixtures may be tried with the hope of success, and even what mixtures may be likely to prove *specific* manures. Thus it is known from analysis that the seeds of plants—the grain of our corn crops, for example—contain much nitrogen in their gluten, and that the ash of grain is rich in phosphoric acid and magnesia. It was natural to suppose, therefore, that the application to growing corn of a mixture capable of specially supplying these three substances would specially act in filling the ear. A saline compound known by the name of phosphate of magnesia and ammonia, containing the two phosphates united,* is fitted for this purpose, and was consequently recommended for trial.

Experiments, recently made, show that it exercises a powerful influence, especially upon Indian corn. Applied at the rate of 130 to 260 lb. per acre, it had also a very favourable, though less marked, influence upon wheat. Upon Indian corn, at the rate of 3 cwt. per acre, it increased the crop of grain six times, and of straw three times. A constant effect is to increase the weight of the grain per bushel as common salt does; and, like many other substances, it produces most marked effects upon poor and worn-out soils.

This compound, therefore, is deserving of further trial; and it is desirable that attempts should be made to manufacture it for the manure-market at a moderate price.†

* It is prepared by pouring mixed solutions of sulphate of magnesia and sulphate of ammonia into a solution of the common phosphate of soda of the shops.

† See the Author's *Experimental Chemistry*, p. 216. Also the *Annales de Chemie* for September 1852, p. 46.

SECTION VI.—RESULTS OF EXPERIMENTS WITH MIXED SALINE MANURES MADE WITH THE VIEW OF AFFECTING THE CHARACTER OR QUALITY OF THE CROP.

The above are illustrations of the kind of mixtures which, on the faith of results obtained by actual trial, may be recommended to the practical man as likely to increase the quantity of the crop. But mixtures may, by the reflecting farmer, be applied for other purposes.

1. As when he mixes together

Nitrate of Soda, . . .	3 cwt.	28 cwt.
Gypsum, ...	5 „	
Wood ashes, ...	20 „	

and applies this mixture at the rate of 5 or 6 cwt. an imperial acre as a cure for clover-sick land—as recommended by Mr Prideaux.

2. Or when two good effects on the growth are sought for at the same time by the simultaneous application of two substances to the crop. Or when an evil effect, considered likely to follow from the use of one substance alone, is to be prevented or counteracted by the use of another substance along with it.

Thus, nitrate of soda applied to corn crops gives increased luxuriance, and greatly promotes the growth of straw, while it also increases the size of the ear. But this rapid growth makes wheat, in some localities, liable to mildew. It is apt also to give a feebleness to the straw, which makes the crop more liable to be laid by the wind and rains; so that if stormy weather come when harvest approaches, the corn may be seriously damaged. On the other hand, common salt, while it usually strengthens and brightens the straw, makes mildew more rare, and adds, besides, to the weight of the grain per bushel. By

using the two substances together, therefore, the increased growth caused by the nitrate will be secured, and mildew probably prevented; while the common salt will give the straw strength to stand. With this view experiments have been made with such a mixture by various persons, with the best results. I quote only two results, obtained at Holkham by Mr Keary, from applications to his wheat crops in 1850 and 1851.

	Application per imperial acre.	Produce. Grain.	Straw.
1850.	No application, . .	37 bush.	26 cwt.
	Nitrate of soda, 1 cwt. .	40 ...	32 ...
	Nitrate of soda, 1 ... } Common salt, 2 ... } .	40 ...	34 ...

In this case the addition of salt produced no increase above the nitrate alone, except in augmenting by 2 cwt. the weight of the straw.

1851.	No application, . .	$37\frac{1}{4}$ bush.	27 cwt.
	Nitrate of soda, 1 cwt. .	$43\frac{3}{8}$ ...	37 ...
	Nitrate of soda, 1 ... } Common salt, 2 ... } .	$45\frac{1}{8}$ ...	36* ...

In this experiment the grain was increased nearly 2 bushels by the salt, while the straw was lessened by 1 cwt. These differences are of little pecuniary consequence. The chief advantage to be looked for from the use of the salt is, as I have said, in its making more sure the gain which nitrate of soda, on all poor soils, and especially upon sickly crops, may be expected to produce.

SECTION VII.—USE OF ARTIFICIAL MIXED MANURES, COMPOUNDED IN IMITATION OF NATURAL MANURES—ARTIFICIAL GUANOS.

The above experiments illustrate how saline mixtures may be made and used for a definite and known purpose,

* *Journal of the Royal Agricultural Society*, vol. xiii. p. 201. See also for similar experiments by Mr Pusey, vol. xii. p. 202.

other than that of simply adding to the natural produce of the land. But mixtures may also be made, with the view of imitating nature, and of compounding by art those valuable manures which she furnishes in such variety, where we can do it effectually, and at a reasonable cost.

Thus guano is a highly fertilising substance; and as the supply brought to this country is limited, and the price at which it was sold, when first introduced into this country, was a great bar to its extensive employment, I was induced at the time to recommend the following, or some similar mixture—as likely to resemble it in fertilising virtue, because it contains the same ingredients, as determined by analysis—to be inexhaustible in supply, because prepared chiefly from the produce of our own manufactories—and to be at least as cheap as the best imported guano.

315	lb. (7 bushels) of bone dust at 2s. 9d. a bushel,	£0	19	0
100	„ sulphate of ammonia, ...	0	14	6
20	„ of pearl ash, or 80 lb. of wood ashes, .	0	4	0
80	„ of common salt, ...	0	1	6
20	„ of dry sulphate of soda, ...	0	2	0
25	„ of nitrate of soda, ...	0	5	0
50	„ of crude sulphate of magnesia, ...	0	1	6
610		£2	7	6

This quantity should be equal in efficacy to 4 or 5 cwt. of guano, and may by many be made at a cheaper rate.

This recipe has formed the basis of numerous varieties of artificial guano which have been manufactured in different parts of the country, and sold under different names, and at various prices—some of them sufficiently low to indicate that either the mixtures are not good, or that they are not made of valuable materials. They have, therefore, been applied to the land with, as might be expected, very discordant results.

Though we should never be able to manufacture an artificial guano equal to the native, this good effect to the

practical man arose at once from the publication of the above *recipe*, and from the manufacture and sale of artificial guano—*that natural guano fell remarkably in price*, and with it rape-dust, bone-dust, and other costly manures of a similar kind. Thus chemistry possesses an intelligible money value even to the working farmer.

This question of cheapness is second only to that of efficiency in a manure. To make these manures cheap is the next point after making them well. With many manufacturers — and unfortunately with many purchasers too—cheapness is made the first consideration; and hence mixtures are brought into the market at a low price, which are of comparatively little value, and can produce a sensibly profitable result in a few cases only, and upon peculiar soils.

To make the manure cheap, the ingredients employed must be so. The refuse of manufactories has been looked to as a source of such cheap materials, and not without the prospect of ultimate advantage to the country. The use of such refuse, however, has, in the first instance, led to much imposition. The exact nature of the refuse must be known, and its uniformity and constancy of composition ascertained, before it can be safely employed in the manufacture of any mixed manure.

It is a great objection to the numerous artificial guanos and mixed manures now offered for sale, that the public have no guarantee, either of the competency of the parties who make them to devise a mixture which shall be universally advantageous—of their ability to select materials which shall render it of that uniform composition which is essential to its success—or of their good faith in endeavouring to secure such a composition.*

* For numerous recipes for particular crops, the reader is referred to the author's *Lectures*, 2d edition, p. 639–646.

CHAPTER XIX.

Use of lime in Agriculture.—Composition of limestones, chalks, corals, shell-sands, and marls.—Burning and slaking of lime, hydrate of lime, spontaneously slaked lime.—Effects of exposure to the air upon quick-lime.—Advantages of burning lime partly mechanical and partly chemical.—Silicate of lime produced by burning.—Quantity of lime usually applied to the land.—Visible improvements produced by lime.—Why liming must be repeated.—How lime is gradually removed from the land.—Circumstances which modify the effects of lime upon the land.—Chemical effects of caustic and of mild lime upon the soil.—What is meant by overliming.—Proportion of lime in overlimed land.—How overliming is to be remedied.—Exhausting effects of lime.—Is lime necessarily exhausting?

THE use of lime is of the greatest importance in practical agriculture. It has been employed in the forms of marl, shells, shell-sand, coral, chalk, limestone, limestone gravel, quick-lime, &c., in almost every country, and from the most remote period.

SECTION I.—COMPOSITION OF LIMESTONES AND CHALKS.

When diluted muriatic acid, or strong vinegar, is poured upon pieces of limestone, chalk, common soda, or common pearl ash, effervescence takes place, and carbonic acid gas is given off, (p. 19.) If a current of this gas be made to pass through lime water, (see figure,) the

liquid becomes milky, and a white powder falls, which is pure *carbonate of lime.* It consists of

	Per cent.
Carbonic acid, ...	43·7
Lime, ...	56·3
	100

One ton of pure dry carbonate of lime contains, of

	Cwts.
Carbonic acid, ...	$8\frac{3}{4}$
Lime, ...	$11\frac{1}{4}$
	20

Limestone and chalk consist, for the most part, of carbonate of lime. In soft chalk, the particles are held more loosely together; in the hard chalks and in limestones, the minute grains have been pressed or otherwise brought more closely together, so as to form a more solid and compact mass.

In regard to limestones and chalks, there are several circumstances which it is of importance for the practical man to know. For example—

a. That they are not composed entirely of mineral or inorganic particles, such as are formed by the passage of a current of carbonic acid through lime-water. They consist in great part, sometimes almost entirely, of minute microscopic shells, of the fragments of shells of larger size, or of solidified masses of corals, which formed coral reefs in ancient seas which once covered the surface where the limestones are now met with. The blue mountain limestones contain many of these coral reefs, while in our chalk rocks vast quantities of microscopic shells and fragments of shells appear.

b. Being thus formed at the bottom of masses of moving water, the chalks and limestones are seldom free from a sensible admixture of sand and earthy matter. Hence,

when they are treated with diluted acid, though the greater part dissolves and disappears, yet a variable proportion of earthy matter always remains behind in an insoluble state. This earthy matter is sometimes less than half a per cent of the whole weight, though sometimes it amounts to as much as 30 or 40 per cent.

c. All animals hitherto examined contain in the parts of their bodies traces more or less distinct of phosphoric acid, generally in combination with lime, forming *phosphate of lime.* This phosphate of lime their remains, when dead, retain in whole or in part. It thus happens that limestones almost invariably contain phosphoric acid, and that the proportion of it usually increases with that of the visible remains of animals, shells, corals, &c., which occur in it. In the magnesian limestones of the county of Durham, I have found the proportion of phosphate of lime to be as small as 0.07 to 0.15 per cent; while in a limestone from Lanarkshire, (Carluke,) analysed in my laboratory, it amounted to $1\frac{1}{4}$ per cent; or one hundred pounds of the burned lime contained as much as $2\frac{1}{3}$ pounds of phosphate of lime.

d. The parts of animals also contain sulphur, and this has given rise to the presence of sulphuric acid in chalks and limestones. This acid exists in them in combination with lime—in the state of gypsum. The proportion of this gypsum which I have hitherto found in native chalks and limestones is small, varying from one-third to four-fifths of a per cent.

e. Carbonate of magnesia, the common magnesia of the shops, is also present, almost invariably, in all our limestone and chalk rocks. In the purest it forms 1 or 2 per cent, in the most impure from 40 to 45 per cent of the whole weight. The rocks called *dolomites* or magnesian limestones, (p. 107,) are characterised by the presence of a large proportion of carbonate of magnesia. In the old red

sandstone formation, also, beds of limestone occur which are rich in magnesia. Such limestones are usually considered less valuable for agricultural purposes. They can be applied less freely and abundantly to the land, and possess what practical men call a burning or scorching quality. They are, however, preferred to purer limes in some districts, as in the high lands of Galloway, for application to hill pastures.

SECTION II.—COMPOSITION OF CORALS, SHELL-SANDS, AND MARLS.

1°. *Corals*, as they are gathered fresh from the sea on the Irish (Bantry Bay) and other coasts, contain, besides carbonate of lime, a small percentage of phosphate of lime, and sometimes not less than 14 per cent of animal matter—(JACKSON.) This animal matter adds considerably to the fertilising value of coral sand, when laid upon the land in a recent state, or when made into compost.

2°. *Shell-sand* consists of the fragments of broken shells of various sizes, mixed with a variable proportion of sea sand. It contains less animal matter than the recent corals, and its value is diminished by the admixture of sand, which varies from 20 to 70 per cent of the whole weight. On the shores of many of the Western Islands, shell-sand is found in large quantities, and is extensively and beneficially applied, especially to the hill-side pastures, and to peaty soils.

3°. *Marls* consist of carbonate of lime—generally the fragments of shells—mixed with sand, clay, or peat, in various proportions. They contain from 5 to as much as 80 or 90 per cent of carbonate of lime, and are considered more or less rich and valuable for agricultural purposes as the proportion of lime increases. They are formed, for the

most part, from accumulations of shells at the bottom of fresh-water lakes which have gradually been filled up by clay or sand, or by the growth of peat.

SECTION III.—OF THE BURNING AND SLAKING OF LIME.

1°. *Burning.*—Limestones, when of a pure variety, consist almost entirely of carbonate of lime. This carbonate of lime, as we have seen, contains about 56 per cent of lime, or 11¼ cwt. to the ton.

When this limestone is put into a kiln, with so much coal as, when set on fire, will raise it to a sufficiently high temperature, the carbonic acid is driven off in the form of gas, leaving the pure lime behind.

In this state it is known as burned lime, lime-shells, caustic lime, and quick-lime, and possesses properties very different from those of the unburned limestone. It has a hot alkaline taste, absorbs water with great rapidity, falls to powder or slakes, and finally dissolves in 732 times its weight of cold water. This solution is known by the name of lime-water.

2°. *Slaking.*—Its tendency to combine chemically with water is shown in the process of slaking. Almost every one is familiar with the fact that, when water is poured upon quick-lime, it heats, emits steam, swells, cracks, and at last falls to a fine, usually white, powder, which is two or three times as bulky as the lime in its unslaked state. When thus fully slaked and cool, the fine powder consists of—

Lime, . . .	76 per cent.
Water, . . .	24 ...
	100

Or 20 cwt. of pure burned lime absorb and retain in the solid state 6⅓ cwt. of water, forming 26⅓ cwt. of slaked lime, called *hydrate* of lime by chemists.

When quick-lime is left exposed to the air, even in dry weather, it gradually absorbs moisture from the atmosphere, and falls to powder without the artificial addition of water. In this case, however, it does not become sensibly hot as it does when it is slaked rapidly by immersion, or by pouring water upon it.

SECTION IV.—OF THE CHANGES WHICH SLAKED LIME UNDERGOES BY EXPOSURE TO THE AIR, AND OF THE BENEFITS OF BURNING LIMESTONES.

1°. *Effects of exposure to the air.*—When lime from the kiln is slaked by means of water, it still retains its quick or caustic quality. But if, after it has fallen to powder, it be left uncovered in the open air, it gradually absorbs carbonic acid from the atmosphere, gives off its water, and becomes reconverted into dry carbonate of lime.

When lime is allowed to slake spontaneously in the air, it first absorbs water, and slakes, and falls to powder, and then absorbs carbonic acid and is changed into carbonate.

But as soon as a portion of the lime slakes, it begins to absorb carbonic acid, probably long before the whole is slaked. Thus the two processes go on together, so that, in lime left to slake spontaneously, as it often is on our fields and headlands, the powder into which it falls consists in part of caustic hydrate, and in part of mild carbonate of lime. Its composition is nearly as follows:—

			Per cent.
Carbonate of lime,			57.4
Hydrate of lime,	lime,	32.4	42.6
	water,	10.2	
			100

When it reaches this stage or composition, the remain-

der of the hydrate absorbs carbonic acid much more slowly, so that, when spread upon or mixed with the soil, it takes a much longer time to convert it into carbonate. At last, however, after a longer or shorter period of time, the whole of the lime becomes saturated with carbonic acid, and is brought back to the same state of mild *un*-caustic carbonate in which it existed in the native chalk or limestone before it was put into the kiln.

2°. *Advantages of burning lime.*—If the lime return to the same chemical state of carbonate in which it existed in the state of chalk or limestone,—what is the benefit of burning it ?

The benefits are partly mechanical and partly chemical.

a. We have seen that, on slaking, the burned lime falls to an exceedingly fine bulky powder. When it afterwards becomes converted into carbonate, it still retains this exceedingly minute state of division; and thus, whether as caustic hydrate or as mild carbonate, can be spread over a large surface, and be intimately mixed with the soil. No available mechanical means could be economically employed to reduce our limestones, or even our softer chalks, to a powder of equal fineness.

b. By burning, the lime is brought into a caustic state, which it retains, as we have seen, for a longer or shorter period, till it again absorbs carbonic acid from the air or from the soil. In this caustic state, its action upon the soil and upon organic matter is more energetic than in the state of mild lime; and thus it is fitted to produce effects which mere powdered limestone or chalk could not bring about at all, or to produce them more effectually, and in a shorter period of time.

c. Limestones often contain sulphur in combination with iron, (iron pyrites.) The coal or peat, with which it is burned, also contains sulphur. During the burning, a

portion of this sulphur unites with the lime to form gypsum, by this means adding to the proportion of this substance, which naturally exists in the limestone.

d. Earthy and silicious matters are sometimes present in considerable quantity in our limestone rocks. When burned in the kiln, the silica of this earthy matter unites with lime to form *silicate of lime.* This silicate of lime, being diffused through the burned and slaked lime, and afterwards spread, in a minute state of division, through the soil, is in a condition in which it may yield silica to the growing plant.

Thus the benefits of burning are, as I have said, partly mechanical and partly chemical. They are mechanical, inasmuch as, by slaking, the burned lime can be reduced to a much finer and more bulky powder than the limestone could be by any mechanical means; and they are chemical, inasmuch as, by burning, the lime is brought into a more active and caustic state, and is, at the same time, mixed with variable proportions of sulphate and of silicate of lime—which may render it more useful to the growing crops.

SECTION V.—QUANTITY OF LIME USUALLY APPLIED TO THE LAND.

The quantity of quick-lime laid on at a single dressing, and the frequency with which it may be repeated, depend upon the kind of land, upon the depth of the soil, upon the quantity and kind of vegetable matter which the soil contains, and upon the species of culture to which it is subjected. If the land be wet, or badly drained, a larger application is necessary to produce the same effect, and it must be more frequently repeated. But when the soil is thin, a smaller addition will thoroughly impreg-

nate the whole, than where the plough usually descends to the depth of 8 or 10 inches. On old pasture lands, where the tender grasses live in 2 or 3 inches of soil only, a feeble dressing, more frequently repeated, appears to be the more reasonable practice ; though in reclaiming and in laying down land to grass, a heavy first liming is often indispensable.

In arable culture, larger and less frequent doses are admissible, both because the soil through which the roots penetrate must necessarily be deeper, and because the tendency to sink beyond the reach of the roots is generally counteracted by the frequent turning up of the earth by the plough. Where vegetable matter abounds, much lime may be usefully added ; and on stiff clay lands, after draining, its good effects are very remarkable. On light land, chiefly because there is neither moisture nor vegetable matter present in sufficient quantity, very large applications of lime are not so usual, and it is generally preferable to add it to such land in the state of compost only.

The largest doses, however, which are applied in practice, alter in a very immaterial degree the chemical composition of the soil. The best soils generally contain a natural proportion of lime, not fixed in quantity, yet scarcely ever wholly wanting. But an ordinary liming, when well mixed up with a deep soil, will rarely amount to *one per cent* of its entire weight. It requires about 400 bushels (12 to 15 tons) of burned lime per acre to add one per cent of lime to a soil of twelve inches in depth. If only mixed to a depth of six inches, this quantity would add about two per cent to the soil.

Though the form in which lime is applied, the dose laid on, and the interval between the doses varies, yet in Great Britain, at least in those places where lime can

be obtained at a reasonable rate, the quantity applied amounts, on an average, to from 7 to 10 bushels a-year.

SECTION VI.—VISIBLE IMPROVEMENTS PRODUCED BY LIME, AND WHY LIMING MUST BE REPEATED.

The most remarkable visible alterations produced by lime are—upon *pastures*, a greater fineness, sweetness, closeness, and nutritive character of the grasses—on *arable lands*, the improvement in the texture and mellowness of stiff clays, the more productive crops, their better quality, and the earlier period at which they ripen, compared with those grown upon soils to which no lime has ever been added.

This influence of lime is well seen when limed is compared with unlimed land, or when soils, which are naturally rich in lime, are compared with such as contain but little. Barley grown on the former is of better malting quality. The turnips of well-limed land are more feeding for both cattle and sheep. And the hill pastures on limestone soils, like those of Derbyshire, continue longer green in autumn, and yield a greater yearly return of milk and cheese, than the soils which are produced from sandstone rocks.

But this superiority gradually diminishes year by year, in land artificially limed, till it returns again nearly to its original condition. On analysing the soil when it has reached this state, the lime which had been added is found to be in a great measure gone. In this condition the land must either be limed again, or must be left to produce sickly and unremunerating crops.

This removal of the lime arises from several causes.

1. *The lime naturally sinks,*—more slowly perhaps in arable than in pasture or meadow land, because the

plough is continually bringing it to the surface again. But even in arable land, it gets at last beyond the reach of the plough, so that either a new dose must be added to the upper soil, or a deeper ploughing must bring it again to the surface.

2. *The crops carry away a portion of lime from the soil.*—Thus the following crops, including grain and straw, or tops and bulbs, carry off respectively—

	Of lime.
25 bushels, wheat, about .	13 lb.
40 ... barley, . .	17 „
50 ... oats, . .	22 „
20 tons of turnips, about .	118 „
8 ... potatoes, . .	40 „
2 ... red clover, . .	77 „
2 ... rye grass, . .	30 „

The above quantities are not constant, and much of the lime is no doubt returned to the land in the straw, the tops, and the manure; yet still the land cannot fail to suffer a certain annual loss of lime from this cause.

3. *The rains wash out lime from the land.*—The rain-water that descends upon the land holds in solution carbonic acid which it has absorbed from the air. But water charged with carbonic acid is capable of dissolving carbonate of lime; and thus year after year the rains, as they sink to the drains, or run over the surface, slowly remove a portion of the lime which the soil contains. Acid substances are also formed naturally by the decay of vegetable matter in the land, by which another portion of the lime is rendered easily soluble in water, and therefore readily removable by every shower that falls. It is a necessary consequence of this action of the rains, that lime must be added more frequently, or in larger doses, where much rain falls than where the climate is comparatively dry.

SECTION VII.—CIRCUMSTANCES WHICH MODIFY THE EFFECTS OF LIME UPON THE SOIL.

There are four circumstances of great practical importance in regard to the action of lime, which cannot be too carefully borne in mind. These are—

1. That lime has little or no marked effect upon soils in which organic—that is, animal or vegetable—matter is greatly deficient.

2. That its apparent effect is inconsiderable during the first year after its application, compared with that which it produces in the second and third years.

3. That its effect is most sensible when it is kept near the surface of the soil, and gradually becomes less as it sinks towards the subsoil. And,

4. That under the influence of lime the organic matter of the soil disappears more rapidly than it otherwise would do, and that, as this organic matter becomes less in quantity, fresh additions of lime produce a less sensible effect.

SECTION VIII. — CHEMICAL EFFECTS OF CAUSTIC LIME UPON THE SOIL.

The chemical effects of lime upon the soil in the caustic and mild states are chiefly the following :—

a. When laid upon the land in the *caustic* state, the first action of lime is to combine immediately with every portion of free acid matter it may contain, and thus to sweeten the soil. Some of the compounds it thus forms being soluble in water, enter into the roots and feed the plant, or are washed out by the springs and rains ; while

other compounds which are insoluble remain more permanently in the soil.

b. Another portion decomposes certain saline compounds of iron, manganese, and alumina which naturally form themselves in the soil, and thus renders them unhurtful to vegetation. A similar action is exerted upon some of the compounds of potash, soda, and ammonia—if any such are present—by which these substances are set at liberty, and placed within the reach of the plant.

c. Its presence in the caustic state further disposes the organic matter of the soil to undergo *more rapid* decomposition—it being observed that, where lime is present in readiness to combine with the substances produced during the decay of organic matter, this decay, if other circumstances be favourable, will proceed with much greater rapidity. The reader will not fail to recollect that, during the decomposition of organic substances in the soil, many compounds are formed which are of importance in promoting vegetation.

d. It is known that a portion at least of the nitrogen which naturally exists in the decaying vegetable matter of the soil is in a state in which it is very sparingly soluble, and therefore becomes directly available to plants with extreme slowness. But when heated with slaked lime in our laboratories, such compounds readily give off their nitrogen in the form of ammonia. It is not unlikely, therefore, that hot lime produces a similar change in the soil, though more slowly—hastening, as above stated, the general decomposition of the whole organic matter, but specially separating the nitrogen, and causing or enabling it to assume the form, first of ammonia, and afterwards of nitric acid, both of which compounds the roots of plants can readily absorb.

e. Further, quick-lime has the advantage of being

soluble to a considerable extent in cold water, forming lime-water. Thus the complete diffusion of lime through the soil is aided by the power of water to carry it in solution in every direction.

SECTION IX.—CHEMICAL EFFECTS OF MILD LIME WHEN APPLIED TO THE SOIL.

When it has absorbed carbonic acid, and become reconverted into carbonate, the original caustic lime has no *chemical* virtue over chalk or crushed limestone, rich shell-sand, or marl. It has, however, the important *mechanical* advantage of being in the form of a far finer powder than any to which we can reduce the limestone by art — in consequence of which it can be more uniformly diffused through the soil, and placed within the reach of every root, and of almost every particle of vegetable matter that is undergoing decay. I shall mention only three of the important purposes which, in this state of *carbonate*, lime serves upon the land.

a. It directly affords food to the plant, which, as we have seen, languishes where lime is not attainable. It serves also to convey other food to the roots in a state in which it can be made available to vegetable growth.

b. It neutralises (removes the *sourness*) of all acid substances as they are formed in the soil, and thus keeps the land in a condition to nourish the tenderest plants. This is one of the important agencies of shell-sand, when laid on undrained grass or boggy lands ; and this effect it produces in common with wood ashes and many similar substances.

c. During the decay of organic matter in the soil, it aids and promotes the slow natural production of nitric acid. With this acid it combines and forms *nitrate of*

lime—a substance very soluble in water—entering readily, therefore, into the roots of plants, and producing effects upon their growth which are very similar to those of the now well-known *nitrate of soda.* The success of frequent ploughings, harrowings, hoeings, and other modes of stirring the land, is partly owing to the facilities which these operations afford for the production of this and other natural nitrates.

SECTION X.—WHAT IS MEANT BY OVER-LIMING?—PROPORTION OF LIME IN OVER-LIMED LAND.—HOW OVER-LIMING IS TO BE REMEDIED.

It is known that the frequent addition of lime, even to comparatively stiff soils long kept in arable culture, will at length so open them that the wheat crop becomes uncertain, and is especially liable to be thrown out in winter.

To lighter soils, again, and especially to such as are reclaimed from a state of heath, and contain much vegetable matter, the addition of a large dose of lime opens and loosens them, often to such a degree that they sound hollow, and sink under the foot. This effect is usually ascribed to an over-dose of lime, and the land is commonly said to be *over-limed.* In this state it refuses to grow oats and clover, though turnips and barley thrive well upon it.

Being desirous of ascertaining the proportion of lime really present in land which had been brought by lime into such a condition, I obtained from Sir George Macpherson Grant a number of soils from different fields upon his estate of Ballindalloch, and caused them to be analysed in my laboratory. The results of the analyses were as follows:—

	Bow-Moon Park—soil.	Bow-Moon Park—subsoil.	Mistly Park—soil and subsoil.	Sutherland Park—soil and subsoil.	Carron Park—soil and subsoil.
Organic matter, . . .	10.29	9.54	5.65	5.73	5.23
Salts soluble in water, .	0.45	0.15	0.50	0.15	0.44
Oxide of iron, ...	2.49	3.68	0.50	0.96	2.04
Alumina, ...	1.71	2.54	1.11	1.48	1.15
Carbonate of lime, . .	1.40	0.69	1.10	0.98	0.67
Oxide of manganese, . .	trace.	0.72	trace.	trace.	0.22
Carbonate of magnesia, .	do.	trace.	do.	do.	trace.
Insoluble matter, chiefly sand, ...	81.77	82.79	91.20	90.34	89.60
	98.11	100.11	100.06	99.64	99.35

In all these soils the quantity of carbonate of lime was much less than is usually found in fertile soils. I inferred, therefore, that the effects ascribed to the lime were not due to its presence in too large a proportion, compared with other soils.

Two other facts aided me in arriving at a correct conclusion upon the subject.

1. That these same soils were known to produce good oats when they had been some years in pasture, or when turnips had been eaten off them with sheep, and the ground thus trodden and consolidated by their feet.

2. That oats and clover prefer a stiffer, stronger soil in which to fix their roots, while turnips and barley delight in a light and open soil.

It was therefore the mechanical, and not the chemical condition of the soils, which caused the failure of the turnip and clover crops. Consolidate them by any means, and these crops would become more certain. The remedies, therefore, were—

a. To eat off the turnips always with sheep;—or

b. To consolidate the loose and open soil by the use of

a heavy roller, a clod-crusher or peg-roller, or other similar mechanical means;—or

c. To use the cultivator as much as possible instead of the plough, and thus to avoid the artificial loosening of the soil which is caused by frequent ploughing.

Still the questions were unsolved,—In what way does the lime produce, or aid the plough in producing, this opening of the soil?—and how are these effects to be prevented in future?

I offer the following considerations, as affording a conjectural explanation of this matter:—

1. The lime, in whatever state it is added to the land, assumes in a short time the state of carbonate.

2. In soils which are rich in decaying vegetables, much acid matter is gradually produced by the action of the air. The acids thus produced decompose the carbonate of lime, and liberate its carbonic acid more or less copiously.

3. The effect of this liberation of the carbonic acid gas *may* be to heave up the land, to loosen it and lighten it under the foot. In heavy lands this may be less perceived, both because they are naturally denser and more difficult to heave up, and because they contain less vegetable matter, and consequently produce less of these acid substances in the soil. In light peaty or thin moorish soils, however, which are rich in decaying plants, the particles of soil are more readily lifted up and separated from one another.

Will this supposed action never cease? It is doubtful if it will, until the nature of the soil is altered—by the gradual removal of the lime—by a diminution of the quantity, and a change in the nature of the decaying vegetable matter—or by a *permanent* solidifying of the land.

This last change may be effected either by a top-dressing of clay, sand, limestone-gravel, or other heavy matter, or by bringing up a heavier subsoil from below. Where the temporary solidification produced by eating off with sheep, and the use of a roller is not approved of, the improvement of *over-limed* land is to be sought for in draining, subsoiling so as to admit the air into the under-soil, and, after a time, in bringing up and mixing with the surface a sufficient portion of this under-soil.

SECTION XI.—EXHAUSTING EFFECTS OF LIME.—IS LIME NECESSARILY EXHAUSTING ?

The exhausting effects of lime have been remarked from the earliest times. It causes larger crops to grow for a certain number of years, after which the produce diminishes, till at length it becomes less than before lime was applied to it. Hence the origin of the proverb that "Lime enriches the fathers and impoverishes the sons."

Two interesting questions, therefore, suggest themselves in connection with this circumstance. How is this exhaustion produced ? Is it a necessary consequence of the addition of lime, or can it be prevented ?

It has already been stated that lime promotes those chemical changes of the organic part of the soil by which it is rendered more serviceable to the growth of plants. But in consequence of this action, the proportion of organic matter in the soil gradually diminishes under the prolonged action of lime, and thus the soil becomes less rich in those substances of organic origin on which its fertility in some degree depends.

Again, lime acts also on the mineral matter of the soil, and prepares it for more abundantly feeding the plant.

Now, as the crops we reap carry off not only organic

but mineral matter also from the soil, anything which prepares that mineral matter more abundantly for the use of the plant must cause also a more rapid diminution of those mineral substances on which, as well as upon its organic matter, the fruitfulness of the soil is dependent.

By this mode of action, therefore, arises the exhaustion which universal experience has ascribed to the use of lime.

But without reference to the chemical processes by which it is brought about, a common-sense view of the question sufficiently explains how the exhaustion arises.

It is conceded that the crops we grow rob the soil both of organic and inorganic matter. A double crop will take twice as much, a triple crop three times as much, and so on. And the more we take out in one year, the more rapidly will the land be exhausted. Now, if lime, by its mode of action, enables us in the same time to extract three or four times as much matter from the soil in the form of increased crops, it must so much the more rapidly exhaust the soil, in the same way as we should drain a well sooner by taking out fifty than by removing only five gallons a-day.

But we can restore to the soil what crops carry off. By farmyard manure, and by saline applications, we can return everything which lime enables us thus to extract, and we can thus preserve its fertility unimpaired. Manure, therefore, in proportion to the crops taken off, and lime, will cease to be exhausting. There is much wisdom in the rhyme,

> "Lime and lime *without manure*
> Will make both land and farmer poor."

CHAPTER XX.

Improvement of the soil by paring and burning. — Use and properties of burned earth and burned clay as improvers. — Effects of burning upon clay.—Smother-burning and over-burning.—How they improve the soil. — Improvement by means of irrigation. — Irrigation a kind of manuring.—How waters manure the land.—Composition of the water of the Hampstead water-works.—Different virtues of natural streams.

THERE remain still a few important modes of improving the soil by forms of mineral and organic manuring, which it is necessary briefly to notice.

SECTION I.—IMPROVEMENT OF THE SOIL BY PARING AND BURNING.

A mode of improvement often resorted to on poor lands is the paring and burning of the surface. The effect of this treatment is easily understood. The matted sods consist of a mixture of much vegetable with a comparatively small quantity of earthy matter. When these are burned, the ash only of the plants is left, intimately mixed with the calcined earth. To strew this mixture over the soil is much the same as to dress it with peat or wood ashes, the beneficial effects of which are almost universally recognised. And the beneficial influence of the ash itself is chiefly due to the ready supply of inorganic food it yields to the seed, and to the effect which the potash and soda, &c., which it contains exercise either in

preparing organic food in the soil, or in assisting its assimilation in the interior of the plant.

Another part of this process is, that the roots of the weeds and poorer grasses are materially injured by the paring, and that the subsequent dressing of ashes is unfavourable to their further growth.

It is besides alleged, and I believe with truth, that poor old grass land, when ploughed up, is sometimes so full of insects that the success of any corn or green crop put into it becomes very doubtful. When pared, these insects collect in the sod, and are destroyed by the subsequent burning.

Paring and burning is a quick method of bringing land into tillage, and will secure one or two good crops. But it is exhausting, and the prudent man will rarely have recourse to it for the purpose of reclaiming land which is to be kept in constant tillage. It is very much less practised now than it was twenty or thirty years ago.

Another evil also follows the practice of paring and burning. Where the land has little fall for drainage—is raised, that is, only a few feet above the level of the nearest brook—this paring and burning gradually lowers the level, and makes it impossible at last to drain it. In Northamptonshire I have been told of pieces of land, a few years ago two feet above the water level, which are now brought down to that level by the repetition of this hurtful practice. This is certainly enriching the fathers and impoverishing the sons.

SECTION II.—ON THE USE AND PROPERTIES OF BURNED EARTH AND CLAY AS IMPROVERS.

1°. *Burned earth* and clay have long been recognised by the farmer as useful applications, in certain circum-

stances, to his land. Mixed with much vegetable matter of any kind, and burned slowly and without free access of air, stiff soils of all sorts will give blackened heaps, which may be spread with advantage as a top-dressing, or employed, as in China, to cover the seed after it has been committed to the earth.

To the light porosity of the earth, and to the action of the vegetable ashes which are mixed with it, the beneficial influence of such burned mixtures is distinctly to be ascribed.

2°. *Burned clay,* in which little organic matter exists, and with which little is mixed during the burning, must owe any fertilising properties it possesses to a different cause. Such clay, properly prepared, has in numerous instances been found beneficial when applied to the land. It is usually laid on in large doses, and acts both mechanically and chemically.

a. Mechanically, in rendering the soil more friable, so that it can be worked with less labour, and in especially aiding the culture of green crops.

b. Chemically, in considerably increasing the produce. Thus Mr Pusey found a dressing of burned Oxford clay to increase his wheat crop from 37¾ to 45½ bushels per imperial acre. And Mr Danger, who farms on the new red sandstone, near Bridgewater, says, that a soil which he found "quite sterile, has, by the application of burned clay, become totally changed."*

It is equally true, however, that burned clay has often failed to do any good—that the practice of burning clay, which is common in some districts, is for this reason never adopted in others—and that clay from the same locality may or may not do good according to the method of burning.

* *Royal Agricultural Journal,* vi. 477, and xii. 509.

All this is easily explained when the true cause of the chemical action of burned clay is understood.

3°. *Cause of its useful chemical action.*—All clays contain sensible quantities of most of the mineral substances —potash, soda, lime, magnesia, phosphoric acid, &c.— which plants require for their healthy growth. They are, however, in a comparatively insoluble condition, which circumstance, united to the stiffness of the clay, prevents the roots of plants from readily taking them up. When the clays are burned by a gentle heat, however, the chemical condition of the constituents of the clay is altered, and the substances which plants require are rendered more soluble. After the burning, both water and acids will dissolve out more from the same weight of dry clay, and the matter thus dissolved contains a large proportion of those mineral ingredients which all plants contain. In one experiment, I found that a ton of clay which, in the natural state, gave to water only 11 lb. of mineral matter, yielded readily 36 lb. after being burned. Besides, the clay is rendered more porous by the burning, so that water and the roots of plants can penetrate more easily to take up the soluble matter.

Again, of burned clay, 50 to 100 tons an acre is not an unusual application. Now, at 36 lb. to the ton, the largest dose would yield to water not less than 3600* lb. of soluble mineral matter; while the whole quantity of such matter carried off in a four-years' rotation, from our best farms, (p. 74,) is only 1300 lb. It is not surprising, therefore, knowing, as we do, how applications of saline matter increase the crops, that so great and ready a supply of such matter in the burned clay should produce a marked effect upon the fertility of the land upon which it is spread.

* *Experimental Agriculture*, p. 261.

But, further, all clays have not the same composition. Some contain more lime, others more magnesia, others more potash or soda, and others more phosphoric acid; while some, again, contain so little of any of these substances as to produce no sensible effect when burned and laid upon the land. Thus the chemical composition of a clay determines whether or not it can be burned and applied with advantage.

Those clays are likely to suit well which contain most alkaline matter, (potash and soda;) next, those which contain a considerable percentage of lime or magnesia, or phosphoric acid; and, best of all, those which with the alkaline contain also the calcareous matter. Hence it is that to clays which contain little lime it is a judicious recommendation that a quantity of slaked lime should be sprinkled upon the clay during its preparation for burning.

In the fourth place, it is remarkable that, by too complete and prolonged a burning, the clay is again rendered less soluble in water and in acids than before. Hence the evil of *over-burning*, as it is called, and the reason why the same clay prepared in different ways does not produce the same good effects. The method of slow *smother*-burning—the heat being kept low, and free access of air prevented—is that which gives the most constant good results.

Lastly, I notice, as a beneficial consequence of burning, that the burned clay, being generally porous, absorbs ammoniacal and other vapours from the air and from the soil, more readily and abundantly than before, and fixes them for the use of plants. In the black smother-burned clay, which contains much iron, this metal, in absorbing oxygen from the air, may even give rise to the formation of ammonia, and thus, in another chemical manner, act favourably upon the soil.

Advantage is taken of this porous quality of burned clay by some English farmers—as by Mr Randall, of Chadbury, near Evesham—to absorb and preserve the droppings of sheep. Under house-fed sheep, kept upon boards or otherwise, a layer of burned clay is spread, upon which the droppings fall: from time to time fresh layers are added to the surface, till it becomes necessary to remove the whole. In this way, the smell of the dung never becomes excessive, and the clay is rendered so rich that 10 tons of it are found equal, in the raising of turnips, to 4 cwt. of guano.

SECTION III.—ON THE IMPROVEMENT OF THE LAND BY IRRIGATION.

The irrigation of the land is, in general, only a more refined method of manuring it. The nature of the process itself, however, is different in different countries, as are also the kind and degree of effect it produces, and the theory by which these effects are to be explained.

1. In dry and arid climates, where rain rarely falls, the soil may contain all the elements of fertility, and require only water to call them into operation. In such cases—as in the irrigations practised so extensively in Eastern countries, and without which whole provinces in Africa and Southern America would lie waste—it is unnecessary to suppose any other virtue in irrigation than the mere supply of water it affords to the parched and cracking soil.

But in climates such as our own, there are several other beneficial purposes in reference to the soil, which irrigation may, and some of which, at least, it always does serve—thus,

2. The occasional flow of *pure* water over the surface, as in our irrigated meadows, and its descent into the drains, where the drainage is perfect, washes out acid and

other noxious substances naturally generated in the soil, and thus purifies and sweetens it. The beneficial effect of such washing will be readily understood in the case of peat-lands laid down to water-meadow, since, as every one knows, peaty soils abound in matters unfavourable to general vegetation. These substances are usually in part drawn off by drainage, and in part destroyed by lime and by exposure to the air, before boggy lands can be brought into profitable cultivation.

3. But it seldom happens that perfectly *pure* water is employed for the purposes of irrigation. The waters of rivers, as they are diverted from their course for this purpose, are more or less loaded with mud and other fine particles of matter, which are either gradually filtered from them as they pass over and through the soil, or, in the case of floods, subside naturally when the waters come to rest. Or in less frequent cases, the drainings of towns and the water from common sewers, or from the little streams enriched by them, are turned with benefit upon the favoured fields. These are evidently cases of gradual and uniform manuring.

4. Even where the water employed is clear and apparently undisturbed by mud, it almost always contains ammonia, nitric acid, and other organic and saline substances grateful to the plant in its search for food, and which plants always contrive to extract, more or less copiously, as the water passes over their leaves or along their roots. The purest spring waters and mountain streams are never entirely free from impregnations of mineral and vegetable or animal matter. Every fresh access of water, therefore, affords the grass in reality another liquid manuring.

5. In illustration of this, I insert the following analysis of the water supplied by the Hampstead Water-works,

for the use of the city of London, as given by Mr Mitchell. It contains in all 40 grains of dry matter to the imperial gallon, which consists of—

Carbonate of lime,	3.83	grains.
Carbonate of magnesia,	3.41	...
Phosphate of lime,	0.28	...
Sulphate of lime,	4.42	...
Sulphate of potash,	3.28	...
Sulphate of soda,	4.81	...
Chloride of sodium (common salt,)	17.76	...
Silica (soluble,)	0.28	...
Crenic acid,	0.17	...
Apocrenic acid,	0.08	...
Other organic matters,	1.72	...
Oxides of iron and manganese,	traces	...
	40.04	...

In this list of substances, we recognise nearly every mineral ingredient which is found in the ash of plants. But, in addition to these ingredients, nearly all river and spring waters contain appreciable quantities of ammonia and of nitric acid, which are not mentioned, and were probably not sought for by Mr Mitchell. It is not surprising, therefore, that waters containing such substances, in an available form, should promote vegetation when used for the purposes of irrigation.

6. The kind of saline substances which spring water or that of brooks contains, depends upon the nature of the rocks or soils from which it issues or over which it runs. In countries where granite or mica slate abounds, potash and soda, and even magnesia, may be expected in notable quantities, while in limestone districts the waters are generally charged with lime. When spread over the fields, these latter waters supply lime to the growing plants, and so affect the general fertility of the soil as to render almost unnecessary the direct application of lime to the land. The value of the mountain streams for the purpose of irrigation in limestone districts is so well

known, that some have been inclined to undervalue all the constituents of natural waters, and to ascribe little worth as irrigators to the clear waters of brooks and springs which are not rich in lime. This opinion, however, is not in accordance with the results of the analyses made in my laboratory, of waters which have been profitably employed for irrigation.

7. Flowing water also drinks in from the air, as it passes along, a portion of the oxygen and carbonic acid of which the atmosphere in part consists. These gaseous substances it brings in contact with the leaves at every moment, or it carries them down to the roots in a form in which they can be readily absorbed by the parts of the plant. It is not unlikely that, in consequence of this mode of action, even *absolutely* pure water would act beneficially if employed in irrigating the soil.

8. Further, the constant presence of water keeps all the parts of the plant in a moist state, allows the pores of the leaves and stems to remain open, retards the formation of hard woody fibre, and thus enables the growing vegetable, in the same space of time, to extract a larger supply of food, especially from the air. In other words, it promotes and enlarges its growth.

In the refreshment continually afforded to the plant by a plentiful supply of water—in the removal of noxious substances from the soil—in the frequent additions of enriching food, saline, organic, or gaseous to the land—in the soft and porous state in which it retains the parts of the plant, the efficiency of irrigation seems almost entirely to consist.

9. To one other interesting point I must advert. It is known that waters which have passed over the surface of a field become sensibly less fertilising. This is easily explained, by the reasonable supposition that the

plants among which they have flowed have deprived them of a portion of their enriching matter.

But, in the same neighbourhood, it has been often observed that waters from natural springs which are perfectly alike in appearance, yet differ remarkably in their value for irrigation. Such is the case among the mountains of the Vosges, where irrigation is much attended to. The same quantity of water, from two neighbouring springs, for example, employed on two adjoining meadows of similar quality, in 1848, gave of hay per acre—

	1st Cutting.	2d Cutting.	Total.
Good spring, . .	58 cwt.	24 cwt.	82 cwt.
Bad spring, . .	14 ...	7½ ...	21½ ...

Or the good spring produced nearly four times as much hay as the bad one.

A chemical examination of the waters of the two springs satisfied the experimenters (Chevandier and Salvetat) that this difference was not due, either

a. To the quantity or kind of the gases which the two waters held in solution ; nor

b. To the quantity or kind of the mineral matters in which both were nearly equally rich ; nor

c. To the quantity of organic matter, of which the bad water in reality contained the most ; nor

d. To the absolute quantity of nitrogen contained in this organic matter—for the bad water actually spread the larger quantity over the soil ; but

e. To the circumstance that the organic matter, though smaller in quantity, was richer in nitrogen. It contained six per cent of this constituent, while that of the poor water contained only two per cent.

This result is in entire consistency with all I have stated on the subject of manures—of the necessity of

nitrogen to the growth of plants (p. 54,)—of the tendency of such as are rich in nitrogen especially to promote growth—and of the influence of organic matters, rich in nitrogen, in enabling plants to work up the mineral and other ingredients in a mixed manure or in the soil, (p. 143,) which may happen to be within their reach.*

* The following extracts in connection with waters *good* and *bad* for irrigating, will interest the reader:—

"There are two brooks on this estate, Delamere, (the property of G. Wilbraham, Esq.,)—one a clear white water, the other brown—both of which abound in trout, and on each there are irrigated meadows. In the former stream the trout are large; in the latter small, and never grow beyond a certain size. The meadows watered by the former are green, luxuriant, and productive; those of the latter comparatively barren. It is supposed that the pernicious effects of the brown stream are occasioned by passing through peat or some mineral substance; but the cause has never been satisfactorily demonstrated."—Mr PALIN, "On the Agriculture of Cheshire," in *Royal Agricultural Journal*, of the Royal Agricultural Society, vol. v. p. 105.

"On the property of the Earl of Caernarvon, near Exmoor, there are four streams;—the Hudson, containing excellent trout, aad making superior water-meadows; the Exe, inferior in the quality of the fish, and less beneficial to grass; the Barle, worse again in each respect; and lastly, the Danes' brook, containing no fish at all, and itself, as I am informed, poisonous to grass land. The variation of their colour confirms Mr Palin's opinion that these differences are owing to the presence of peat."—PH. PUSEY, *ibid.*, *Note.*

As a pendent to these home cases, I add the following regarding a foreign river in different parts of its course:—

"I ought to mention of the Tochee, that so long as it remains in Bunnoo, its waters are used both for irrigation and household purposes, and I never heard any complaint of it in either of these departments. But, changing its qualities with its name, in Murwut, the Goombeeluh, as it is now called, is deemed useless for agriculture; and though habit enables the natives to drink it with impunity, it is very injurious to strangers, producing, after a few days, and sometimes hours, great pain and inflammation."—*A Year on the Punjab Frontier in* 1848–49, by Major HERBERT B. EDWARDS. Vol. i. p. 68.

CHAPTER XXI.

The Products of vegetation. — Influence of different manures on the quantity of a corn crop.—Average composition of the grain of wheat, and influence of climate upon that composition. — Influence of manure on the proportion of gluten and yield of flour.—Experiments of Mr Burnet.—Composition of the oat, and influence of variety on its composition and nutritive quality. — Composition of barley, and influence of circumstances on its sprouting, melting, and feeding properties.—Composition of rice, maize (Indian corn), and buck-wheat. — Composition of the bean, the pea, and other leguminous seeds. — Composition of oily seeds, and nuts, and of the acorn.— Relation of the quality of the soil to the quality of our corn crops.

THE first object of the practical farmer is, to reap from his land the largest possible return of the most valuable crops, without permanently injuring or exhausting the soil. With this view he adopts one or other of the methods of treatment above adverted to, by which either the physical condition or the chemical composition of the soil is altered for the better. It may be useful to show how very much both the quantity and the quality of a crop is dependent upon the mode in which it is cultivated and reaped, and how much control, therefore, the skilful agriculturist really possesses over the ordinary productions of nature.

SECTION I.—OF THE INFLUENCE OF MANURE ON THE QUANTITY OF THE WHEAT AND OTHER CORN CROPS.

Every one knows that some soils naturally produce much larger returns of wheat, oats, and barley than others

do, and that the same soil will produce more or less according to the mode in which the land has been prepared —by manure or otherwise—for the reception of the seed. The following table shows the effect produced upon the quantity of the crop by *equal quantities* of different manures applied to the *same soil*, sown with an equal quantity of the same seed:—

	Return in bushels from each bushel of seed.			
Manure applied.	Wheat.	Barley.	Oats.	Rye.
Blood, . . .	14	16	12½	14
Nightsoil, . .	—	13	14⅓	13½
Sheep's dung, .	12	16	14	13
Horses' dung, .	10	13	14	11
Pigeons' dung, .	—	10	12	9
Cows' dung, . .	7	11	16	9
Vegetable manure, .	3	7	13	6
Without manure, .	—	4	5	4

It is probable that on different soils the returns obtained by the use of these several manures may not be uniformly in the same order, yet it will always be found that blood, nightsoil, and sheep, horse, and pigeons' dung, are among the most enriching manures that can be employed. (See table in p. 237-8.)

It is a practical fact, bearing upon this point, that in some parts of Bedfordshire, high-farming causes barley to run to straw, to the injury of the corn; while, on the contrary, the wheat increases in yield with higher cultivation.*

Two facts will particularly strike the practical man on looking at the above table.

1. That, exclusive of blood, sheep's dung, in these experiments, gave the greatest increase in the barley crop. The favourite Norfolk system of eating off turnips with sheep previous to barley, besides other benefits which are known to attend the practice, may possibly owe part of

* CAIRD'S *English Agriculture*, p. 451.

its acknowledged utility to this powerful action of sheep's dung upon the barley crop. Still, too much reliance is not to be placed on such special results till the experiments have been carefully repeated.

2. The action of cows' dung upon oats is equally striking, and the large return of this crop (thirteen-fold) obtained by the use of vegetable manure alone, may perhaps explain why, in poorly farmed districts, oats should be a favourite and comparatively profitable crop, and why they may be cultivated with a certain degree of success on land to which rich manure is rarely added.

It is possible, I repeat, that results different from those recorded in the above table may be obtained by a careful repetition of the same experiments on soils of different kinds, and in different circumstances. It is very desirable, therefore, that such experiments should be undertaken, accurately conducted, and carefully recorded.

SECTION II.—AVERAGE COMPOSITION OF THE GRAIN OF WHEAT, AND INFLUENCE OF CLIMATE ON THAT COMPOSITION.

The grain of wheat consists, on an average, of

Water,	14.0
Fatty matter,	1.2
Protein compounds, Gluten and albumen,	14.6
Starch and dextrin,	66.9
Cellular fibre,	1.7
Mineral matter,	1.6
	100

This average composition does not truly represent the composition of our British and European varieties of wheat. It makes the proportion of protein compounds rather too large. Climate and season are believed to

influence the proportion of gluten, so that the grain of warm climates and hot seasons is generally richer in this ingredient. Thus four varieties gave to Peligot:—

	Flemish.	French.	Polish. Grown in France.	Egyptian. Grown in France.
Water, . .	14.6	14.6	13.2	13.5
Fat, . . .	1.0	1.3	1.5	1.1
Protein compounds,	10.7	9.9	21.5	20.6
Starch, &c. .	71.9	74.2	61.9	64.8
Cellulose, . .	1.8	?	?	?
Mineral matter, .	?	?	1.9	?
	100	100	100	100

The increased proportion of protein compounds in the samples of Polish and Egyptian wheat is very remarkable; and it is not less interesting that they had been grown in France from the foreign seed. This latter fact illustrates—what every practical farmer is familiar with—that imported seed always retains for some seasons the peculiar qualities which distinguish it in the country from which it is brought. It is not to be supposed that all varieties of wheat from Poland or Egypt contain the large proportion of gluten found by Peligot in the above varieties, which must, I believe, be regarded as very rare and extreme cases. An increase of 2 or 3 per cent in the protein compounds is the most that can reasonably be expected in Eastern compared with British wheat; and even this is by no means constant, as it is modified by season, by modes of culture, and by other causes.

SECTION III.—INFLUENCE OF THE KIND OF MANURE ON THE PROPORTION OF GLUTEN IN WHEAT, AND ON THE YIELD OF FLOUR.

Among these *other* modifying causes may be mentioned the kind of manure by which its growth is assisted.

That this is really capable of altering the proportion of gluten contained in the grain, is very probable; though it has not as yet been experimentally established that it is capable of doing so in a very great degree.

Another influence of manure upon the grain of wheat appears less uncertain—that is, the proportion of fine flour which the grain will yield when sent to the mill. This is somewhat strikingly illustrated by the following experiment:—

The same variety of wheat, top-dressed with the same rich manure — *sulphated urine*, (p. 224,) mixed with different saline substances—and grown in the same season on the same fields, gave Mr Burnett of Gadgirth—

Manure.	Produce per acre. In bush.	Fine flour from the grain. Per cent.	Gluten in the flour. Per cent.
No manure, ...	31½	76	9⅓
Sulphated urine and wood-ashes, .	40	66	10⅓
Do. and sulphate of soda, . .	49	63	9¾
Do. and common salt, . . .	49	65	9½
Do. and nitrate of soda, . .	48	54	10

In these results we see, *first*, that the produce of fine flour from the grain is very different in the different samples; and, *second*, that the rich top-dressings did not very largely increase the proportion of gluten in the flour.

The whole produce of gluten in the crop was increased, because the crop was increased in quantity; but in none of the experiments was the percentage of gluten largely augmented. A flour peculiarly rich in gluten is required —such at least is the prevailing opinion—for the manufacture of macaroni and vermicelli; and such is said to be the quality of the grain naturally produced in southern Italy. Further experiments are required to show how far, by what means, and in what circumstances, the percentage of protein compounds can in this country be

economically increased by the management of the cultivator.*

SECTION IV.—COMPOSITION OF THE OAT, AND INFLUENCE OF VARIETY ON ITS COMPOSITION AND NUTRITIVE QUALITIES.

The following analyses of two samples of Scotch oats, made in my laboratory by Professor Norton, will show the relative proportions in which the several constituents exist in this kind of grain, and the amount of variation which these relative proportions are liable to undergo in this country in different varieties :—

Composition of Oats dried at 212° *Fah.*

	Potato Oats.	Hopetoun Oats.
Starch,	65.60	64.80
Gum,	2.28	2.41
Sugar,	0.80	2.58
Oil,	7.38	6.97
Avenin,†	16.29	16.26
Albumen,	2.17	1.29
Gluten,	1.45	1.46
Husk,	2.28	2.39
Ash,	2.60	2.32
	100.85	100.48

The united percentage of the three varieties of *protein* compounds (within the bracket) in the oat is very large; and hence the very nutritive quality of this grain. But the quality of the oat, like that of wheat, varies with the soil, the climate, the manure, and the variety. As an instance of the latter, I may mention that the hinds in many parts of Scotland live only on oatmeal, of which

* In the neighbourhood of Kirkcaldy wheat is said to be poorer after early-lifted than after ripe potatoes. Is this the case ?—and if so, how is it to be explained ?

† See page 50.

they are allowed two pecks each a-week. If made from potato oats, the two pecks are often insufficient; but when made from the common Angus oat, this quantity is frequently more than the hind can consume.

SECTION V.—INFLUENCE OF VARIETY ON THE QUANTITY OF PRODUCE, AND ON THE PROPORTION OF MEAL YIELDED BY THE OAT.

The quantity, as well as the quality, of the grain of the oat yielded by the same soil is much affected by the variety of oat which is sown. The proportion of meal yielded by an equal weight of the grain is also materially affected by the variety. This is shown by the following table of the results obtained by Mr Hay from eight different varieties of oats well known in Scotland. The experiment was made in the year 1850, upon a thorough drained field of stiff cold clay with a retentive subsoil. All the varieties were sown on the 26th and 27th of March, all reaped between the 20th and 26th of August, and the extent of each experimental plot was three quarters of an imperial acre.

Variety.	Produce		Meal yielded by 100 lb. of grain.
	Grain.	Straw.	
	bush.	cwt.	lb.
Potato oat, . .	69	62½	60⅓
Sheriff	65¾	55½	52⅓
Berlie	55½	55½	58
Hopetoun	56½	56¾	60½
Blainslie	52¼	60½	51¾
Sandy	47	48½	60
Early Angus	48¼	45¾	55⅔
Barbachla	45	49	60½

The differences in each of these three columns are very striking, and will suggest to the reader many interesting

considerations, to which space does not permit me here to advert.

I only add, that, in all the different grains we cultivate, variety is found to affect in a similar manner the quantities of produce reaped.

SECTION VI.—OF THE AVERAGE COMPOSITION OF BARLEY.

The Scotch oat is the most nutritious of our home-grown grains. Among the ancients, barley was highly esteemed for its feeding qualities. The Greeks, Egyptians, and Hebrews made much use of it, and the wrestlers and gladiators ate only barley bread; hence they were called *hordearii.** It is still recognised in this country as possessed of great feeding power, though the higher price obtained for samples which malt well has thrown somewhat into the shade its purely nutritive qualities.

The average composition of fine barley meal is nearly as follows:—

Water,	14
Protein compounds,	14
Starch &c.,	68
Fatty matter,	2
Mineral matter,	2
	100

The above is exclusive of the bran separated by the miller, which forms from 10 to 18 per cent of the weight of the grain. It shows the flour to be very nutritious, containing 14 per cent of the protein or flesh-forming constituent, while fine wheaten flour rarely contains more than 10 per cent.

* PLINY, Book xviii.

SECTION VII.—INFLUENCE OF CIRCUMSTANCES ON THE SPROUTING, MELTING, AND FEEDING QUALITIES OF BARLEY.

1°. *Malting qualities.*—The *malting* of barley is known to be affected by various circumstances. Unless the grain be dry, it does not sprout readily, and hence it is customary for maltsters to *sweat* their barley on the kiln before malting it. The grain should also be so uniform in ripeness as to sprout uniformly, so that no part of it may be beginning to shoot when the rest has already germinated sufficiently for the maltster's purpose. On this perfect and uniform sprouting of the *whole* depends in some degree the swelling of the malt, which is of considerable consequence to the manufacturer.

The uniformity of sprouting depends sometimes on the mode of husbandry practised where it is grown. Thus when barley is taken after turnips, if the land be merely cross-ploughed, the manure which had been laid in the turnip drills will remain in lines along the field where the turnips had grown, and the barley along those lines will ripen first. But if the land be ploughed *diagonally*, the manure will be equally spread and the barley nourished and ripened equally, and thus it will be likely to sprout uniformly also.

But the *melting* quality of the grain, which is of more consequence to the brewer and distiller, is understood to be modified chiefly by the proportion of gluten which the barley contains. That which contains the least gluten, and, therefore, the most starch, is supposed to melt the most easily and the most completely, and to yield the strongest beer or spirit from the same quantity of grain. Hence the preference given by the brewer to the malt of particular districts, even where the sample appears other-

wise inferior. Thus the brewers on the sea-coast of the county of Durham will not purchase the barley of their own neighbourhood, if Norfolk grain can be had at a moderate increase of price. But that which refuses to melt well in the hands of the brewer, will cause pigs and other stock to thrive well in the hands of the feeder, and this is the chief outlet for the barley which the brewer and distiller reject.

2°. *Feeding qualities.*—So far as a practical deduction can be drawn from the experiments hitherto made in regard to the effects of different manures upon the proportion of gluten in barley, it would appear that the larger the quantity of cows' dung contained in the manure applied to barley land—in other words, *the greater the number of stock folded about the farmyard, the more likely is the barley to be such as will bring a high price from the brewer.*

The folding of *sheep* appears to produce a larger return from the barley crop, and the folding of *cattle* to give grain of a better quality. These points also, however, require to be elucidated by more careful experiment. Such statements stand in our books at present rather as guesses at the truth, than as deductions from rigorously made observations.

SECTION VIII.—COMPOSITION OF RYE, RICE, MAIZE (INDIAN CORN), AND BUCKWHEAT.

These four species of grain contain, respectively, when dried at 212° Fahr., of—

	Rye.	Rice.	Maize.	Buckwheat.
Starch, &c., . .	78.0	87.4	71.6	60.6
Protein compounds,	12.5	7.5	12.3	10.7
Fatty matter, .	3.5	0.8	9.0	0.4
Husk, . . . } Mineral matter, . }	6.0	3.4	5.9	26.0
		0.9	1.2	2.3
	100	100	100	100

These numbers, it will be understood, are liable to variation in different samples; especially the quantity of protein compounds in rye varies, and that of the fatty matter or oil contained in Indian corn. In some varieties of the latter grain this oil is only 2 to 3, in others as much as 9, per cent of the dry cone.

In their natural undried state they all contain 14 to 15 per cent of water. It will be seen that, in so far as the protein or muscle-forming ingredients are concerned, rice is the least, and rye and maize the most nutritious of these four varieties of grain.

SECTION IX.—COMPOSITION OF THE BEAN, THE PEA, AND OTHER LEGUMINOUS SEEDS.

The bean, pea, lentil, vetch, &c., are distinguished from *white* corn by the large proportion of protein compounds they contain, and their consequently greater nutritive power. They resemble each other very much in composition; and in the state of dryness in which they are generally brought to market, as field crops, they consist of about—

Water,	14
Starch and sugar,	48
Protein compounds, (legumin,)	24
Fatty matter,	2
Husk,	10
Mineral matter,	2
	100

The proportion of husk varies; the pea, which contains 10 per cent, having generally a thinner, and the bean a thicker skin. The proportion of protein compounds varies from 20 to as high as 30 per cent; and, according to experiment, the kind of manure employed materially influences this proportion. Manures rich in nitrogen cause it to increase. It is also an interesting fact, that

the young legumes, when just beginning to form in the shell, are exceedingly rich in protein compounds. The very young pea, for example, contains as much as 48 per cent; while, as the above table shows, the ripe pea rarely contains more than 24 per cent (p. 55.)

The kind of protein compound which exists in these grains possesses peculiar chemical properties, and has been called legumin, (p. 50;) but its nutritive qualities are believed to be very much the same as those of gluten and albumen.

SECTION X.—COMPOSITION OF THE OILY SEEDS AND NUTS, AND OF THE ACORN.

Many seeds, like those of flax and rape, contain a much larger quantity of oil than the kinds of corn which are usually employed as food for man. The same is the case with nuts. From the kernels of the walnut, for example, and from those of the sweet almond, upwards of half their weight of oil can often be extracted.

1. *Linseed and linseed cake.*—Linseed contains from 20 to 30 per cent of oil. A large proportion of this is squeezed out in the oil mills, and sold under the name of linseed oil. The *cake* or residue which remains, still contains a considerable proportion of oil; and, as it is very nutritive, is extensively employed in the feeding of cattle. The relative values of the seed and the cake for feeding purposes, and the value of both compared with other kinds of food, is shown very nearly by the following table:—

	Composition of	
	Linseed.	Linseed cake.
Water,	9	10
Protein compounds,	19	22
Starch, &c.,	34	39
Oil,	25	12
Husk,	8	9
Saline mineral matter,	5	8
	100	100

Both seed and cake, therefore, are very nutritious; and even the pressed cake still contains more fatty matter than Indian corn, some varieties of which contain as much as 9 per cent.

What is called starch in the above analyses is, in reality, a kind of mucilage or gum, which dissolves readily in water, but serves the same purposes as starch in the feeding of animals.

2. *Rape cake* is about of equal nutritive value with linseed cake, but is often refused by cattle on account of its hot and acrid taste: this repugnance, however, may be overcome by mixing the crushed cake with a small quantity of molasses, or by boiling it into a jelly with one-third of bean-meal, and making this into a mess with cut straw or hay. Sheep eat it readily when fed upon cabbage, and if kept upon other green food they soon become accustomed to it, if copiously supplied with water. The lower market price of rape cake makes a knowledge of these circumstances of money value to the practical feeder.

3. Nuts resemble the oily seeds in their composition; and hence *nut-cakes* approach linseed cake in value as a food for cattle.

4. The acorn is also very nutritious, though it does not contain much fatty matter. As it falls ripe from the tree it consists of—

Water,	32
Protein compounds,	15
Starch and sugar,	47
Fatty matter,	3
Cellular fibre,	2
Mineral matter,	1
	100

Were the acorn made as dry as the bean is usually sold, it would, weight for weight, be nearly as nutritive. Hence the fattening of pigs when turned into oak

forests, the use of the common acorn in periods of famine in many countries, and the constant use of the sweet acorn, (that of the *Quercus gramuntia* of Linnæus,) in parts of Spain and Sardinia, as a common food of the people. A sweet acorn is also regularly found in the North African markets of Constantine, Bona, and Algiers.

The acorn is remarkable for containing as much as 7 per cent of sugar, of which a small portion is sugar of milk. Could the bitter astringent substance, which gives our common acorns their unpleasant taste, be readily extracted, it might become an acceptable article of food in every country.

SECTION XI.—INFLUENCE OF THE CONDITION AND QUALITY OF THE SOIL ON THE QUALITY OF OUR CORN CROPS.

We have already shown that the quantity of the crop is materially affected by the character of the soil, but the quality of the produce is no less affected by the same cause. Thus—

1. *Barley.*—The varying quality of this grain raised in different localities is familiar to every farmer. On stiff clays, barley may yield a greater produce, (North Hampshire,) but it is of a coarser quality. On light chalky soils it is thin-skinned, rich in colour, and, though light in weight, well adapted for *malting;* while on loamy lands and on sandy marls it assumes a greater plumpness, yet still retains its malting quality.*

2. *Wheat.*—Similar differences affect the same variety of *wheat* when grown upon different soils. In a previous Section it was stated that the quantity of gluten con-

* See p. 104, on the growth of the *Ware malt.*

tained in wheat is believed to vary with the climate, and in some degree also with the manure applied to the land; but a similar variation occurs on unlike soils, when manured, or otherwise treated in every respect alike. The miller knows by experience the relative qualities of the wheat grown on the several farms in the neighbourhood of his mill, so that even when his eye can detect no difference of quality between two samples, a knowledge of the places where they were grown enables him to decide which of the two it will be most for his interest to buy.

3. The *oat* varies in quality likewise with the soil on which it is grown. The meal made from oats grown upon clay land is the best in quality, is the *thriftiest*, keeps the longest, and generally brings the highest price.

I lately visited a farm in Forfarshire, part of which consisted of a sharp gravelly soil on a slope, and part of flat boggy land, resting on marl. Oats were usually grown on both soils, and I asked what difference the tenant observed in the quality of the grain he obtained from each. "In appearance," he answered, "there is no difference; I could take the samples to market, and get the same price for each. If I wanted them for *seed*, I would buy either of them indifferently at the same price; but for meal for my own eating, I would give two shillings a boll more for the oats of the sharp land. The sharp land *meal*," he added, "gives a dry *knotty brose* and a *short* oatcake; that from the bog land may do for porridge, but it makes bad soft brose, and a tough cake."

4. *Rye* also flourishes upon light and sandy soils in general, but when grown upon sandy marls it is found (in Germany) to yield much brandy.

5. The *pea* and the *bean* are distinguished by similar peculiarities, when grown in light and in heavy soils.

There are certain spots in the neighbourhood of all large towns, which are known to produce the best boiling peas,—such as boil soft and mealy. Thus the gravelly slope of Hopwas Hill, near Tamworth, on the Lichfield road, grows the best *sidder* or boiling green peas for the Birmingham market; the Vale of Tamworth in general growing only *pig* peas—hard boilers used only for feeding. Lime and gypsum are said by some to impart the boiling quality, while by others exactly the reverse is stated. No doubt the different results are owing to differences in the soils upon which the several experiments were made.

It is a remarkable circumstance, that on the London corn exchange, the dealers seldom buy British peas without first sending a sample to be boiled,—while foreign peas are generally bought without any trial. They are almost invariably boilers. For split peas, used in making soups and pease-meal, it is obvious that this boiling quality is of great importance.

The explanation of all these differences is, to a certain extent, simple. The relative proportions of gluten and starch in all vegetable juices, and seeds, is variable. The plant is fitted to flourish, to live in a comparatively healthy manner, and to perform all its natural functions, although the supply of those kinds of food out of which its gluten is formed be greater or less within certain limits; but the boiling, feeding, malting, or distilling qualities of its stems, seeds, or roots will be materially affected by variations in this supply.

Again, the proportion of gluten seems to be dependent upon the quality of the soil, not only because the nitrogen it contains is chiefly imbibed by the roots of the plant, but because this gluten is always associated with a certain small quantity of sulphur, phosphorus, and earthy matter, which can only be derived from the soil. Where

these elements abound in the neighbourhood of the roots, the plant may produce much gluten; where they are absent, it may not; so that the feeding and other important qualities of the plant depend no less upon the presence of sulphur and phosphorus in the soil, than upon that of any of the so-called organic elements of which its several parts are principally made up.

Still it must be borne in mind, that these explanations of the differences observed on the corn exchange, and by the miller, are as yet hypothetical. The causes stated *may* produce the effects actually observed, but it has not been proved, by analytical and other experiments, that they really do produce them. Mere age induces changes in the qualities of grain, such as I have described, which the miller values and is willing to pay for.

CHAPTER XXII.

Average composition of the potato, turnip, mangold-wurtzel, and carrot.—Influence of soil, variety, manure, &c., on the quality of the potato and the quantity of starch it contains.—Influence of soil, season, variety, and manure on the composition and feeding properties of the turnip.—Composition of the cabbage, cauliflower, mushroom, turnip-top, and of hay, straw, and the leaves of trees.—Composition of fruits, and the effect of soil upon their quality and flavour.—Relative quantities of starch and gluten contained in our usually cultivated crops.—Quantity of oil or fat in grain, root, and hay crops.—Absolute quantity of food yielded by an acre of land under different crops.

SECTION I.—AVERAGE COMPOSITION OF THE POTATO, TURNIP, MANGOLD-WURTZEL, AND CARROT.

1. The turnip tribe differs from the potato in two principal points.

a. In the quantity of water they respectively contain. In the potato this forms three-fourths, but in the turnip nine-tenths, of the whole weight, when taken from the ground: or they consist of—

	Potato.	Turnip.
Water,	75	91
Dry nutritive matter,	25	9
	100	100

b. In the presence of starch in the potato, while the turnip contains in its stead a substance—pectose or pectic acid—which contains more oxygen than starch, but serves the same purposes in the nutrition of animals, (p. 46.)

2. The dry nutritive matter of the potato and turnip contains, on an average, about—

	Potato.	Turnip.
Starch or pectose, . . .	62	15
Sugar and gum, . . .	15	56
Protein compounds, . . .	9	15
Fatty matter, ...	1	2
Cellular fibre, ...	9	7
Mineral matter, . . .	4	5
	100	100

This table shows also that the turnip contains more sugar than the potato, and is richer also in protein compounds. Hence the advantage derived from, and the preference generally given to it, in the feeding of stock.

3. The dry matter of the mangold-wurtzel and the carrot resembles in composition that of the turnip. Some varieties of these roots contain still more sugar. They likewise surpass the turnip in their per-centage of dry nutritive matter. This, in the three roots, is nearly as follows:—

	Turnip.	Mangold.	Carrot.
Dry nutritive matter,	8 to 12	15	14 to 20
Water, . .	92 to 88	85	86 to 80
	100	100	100

Hence the generally more nutritive quality of the two latter roots, weight for weight.

SECTION II.—INFLUENCE OF SOIL, VARIETY, DEGREE OF RIPENESS, KIND OF MANURE, AND OTHER CIRCUMSTANCES, ON THE QUALITY OF THE POTATO, AND THE QUANTITY OF STARCH IT CONTAINS.

The potato is a crop of so much importance in this country, that it may be interesting to introduce a few more detailed remarks in regard to the variations which

the quality, and especially the proportion of starch contained in it, has been found to undergo.

1. *Influence of soil.*—It is familiarly known to the potato grower, that clay soils produce waxy, and sandy soils mealy potatoes. But the condition of the land also exercises a material influence both upon their growth and quality. When, for example, potatoes are planted in rich newly broken-up land, they run up greatly to *shaws* or tops, produce generally few or small tubers, and of bad eating quality, because they seldom ripen before the frost sets in. Thus in one case it was remarked by Mr Thompson, of Kirby Hall, York, that *black kidneys* planted on such a soil seemed quite to have changed their character. Instead of the fine mealiness for which they are usually remarkable, they bore much more resemblance to *a piece of yellow soap*. They, however, proved excellent seed, and in the wet summer of 1843 showed no failures, and gave a capital crop. They were certainly not ripe, and to this circumstance Mr Thompson ascribed their badness for eating and their goodness for seed.

Again, it has been observed that the quantity of starch is larger in potatoes which are grown upon land long in arable culture than upon such as is newly brought into cultivation or broken up from grass. Thus Mr Stirrat states, that from one peck of potatoes grown upon land near Paisley, which had been almost constantly under crop for the last thirty years, he obtained 7 lb. of starch, while another peck grown on his bleach-green, newly broken up, gave him only 4 lb.*

2. *Influence of variety.*—On the same soil, different varieties produce different proportions of starch. Thus, in 1842, Mr Fleming, of Barochan, obtained from four

* See the Author's *Lectures on Agricultural Chemistry and Geology*, 2d edit. p. 901.

varieties of potato grown on his farm, the following per-centage of starch :—

Connaught Cups, . . .	21 per cent.
Irish blacks, ...	16¼ ...
White Dons, . . .	13 ...
Red Dons, ...	10¾ ...

These differences in the per-centage of starch become very striking when we calculate the relative quantities *per acre* yielded by these varieties. Thus, under similar treatment, they gave respectively—

	Produce per acre. Of potatoes.	Of starch.
Cups, . . .	13½ tons.	2.9 tons.
Red Dons, . .	14½	1.5
White Dons, . .	18½	2.4

So that the lightest crop gave the most starch. ***Though five tons an acre heavier, the crop of white Dons gave half a ton less starch than the Connaught Cups.***

3. *Effect of manures.*—I have already mentioned the alleged influence of sea-weed, (p. 164,) and of skin parings, (p. 181,) in making potatoes waxy. It is not so surprising, therefore, that the kind of manure employed should affect in a sensible degree the proportion of starch yielded by the potato. Thus Mr Fleming found his potatoes raised with different manures in 1843, to give the following per-centage of starch :—

	Per cent.
1. Cups with dung alone, gave .	14.5 of starch.
———— and guano, .	14.4 ...
2. White Dons with *guano* alone, .	9.0 ...
———— and dung,	10.2 ...
3. Rough reds with guano alone, .	15.7 ...
———— and dung,	17.1 ...
4. Perth reds with guano alone, .	15.3 ...
———— and dung,	15.5 ...

These experiments show, *first*, that, in so far as the proportion of starch is concerned, either dung alone, or half

guano and half dung, may be used with equal advantage. The experiment upon the Cups shows this. *Second*, that a mixture of dung and guano is in this respect better than guano alone.* All the other trials show this,—while they show further, also, how much the proportion of starch depends upon the variety of potato we grow.

These varying proportions of starch are of much moment to the practical farmer at the present time, when potato failures are so common,—inasmuch as *the certainty of the growth of the potato, when used as seed, appears to be the greater, the smaller the per-centage of starch.*

4. *Effect of other circumstances.*—I advert briefly to three other circumstances which affect the quantity of starch contained in the potato.

a. The effect of keeping is to diminish the quantity of starch. Potatoes which in October yielded readily 17 per cent of starch, gave in the following April only 14½ per cent.

In connection with the keeping of the potato, it is a very interesting fact, that the epidermis or outer covering of the skin consists of a thin layer of *cork*, without visible pores, and through which water passes with extreme slowness. Hence the potato can be kept for months at a temperature of 86° Fahrenheit, without losing more than three per cent of its weight.

b. The effect of frost is also to lessen the starch. It acts chiefly upon the vascular and albuminous part, but it also converts a portion of the starch into sugar, hence the sweetish taste of frosted potatoes.

c. The heel end of the potato contains more starch than

* This arises from the tendency of the potato to rush up to stalk when manured with guano alone,—the effect of the guano being more or less exhausted before the plant reaches maturity, or has time to form its tubers. When mixed with dung, the latter carries on the growth which the former may have left unfinished.

the rose end, and both more than the central part. Thus a variety of red potato which yielded 21 per cent of starch from the heel end, gave me only 16½ from the rose end, and 14 per cent from the central part.

SECTION III.—INFLUENCE OF SOIL, SEASON, VARIETY, AND MANURE, ON THE COMPOSITION AND FEEDING PROPERTIES OF THE TURNIP.

1. *Soil.*—That the soil has an influence on the composition of the turnip crop, has long been believed by the practical man, because of the difference in the taste and feeding properties of the same kind of turnip grown on different fields and farms.

The chemical nature of this difference has lately been investigated by Dr Anderson. His analyses of turnips, grown in the same season and circumstances, upon

a. The heavy alluvial clay of the Carse of Gowrie;

b. The black land which separates the clay from the hill, and there, as in Lincolnshire, skirts the slopes;

c. The hill land, which is a light loam—

showed that the proportion of nitrogen or of protein compounds was almost always greater on the hill land than on either of the other soils—sometimes *twice as great.* The turnips of the black land were also slightly superior in this respect to those of the clay. This result of analyses fully supports that of practical experience in the feeding of stock.

2. *Season.*—The same analyses have confirmed another opinion of practical men, that the turnips of different seasons differ in their nutritive properties. Thus, in 1850, the turnips, from all the varieties of soil above mentioned, contained a smaller per-centage of protein compounds than in 1849, and the differences among them

were less. The proportion of phosphates was also considerably less in the turnips of 1850.

3. *Variety.*—The influence of variety is more striking, perhaps, on the turnip than upon any other of our more largely cultivated crops. The swede not only keeps better and longer, but is also sweeter and more nourishing than the white globe or yellow turnip. Hence in our large towns, when swedes, as they sometimes do, sell for 30s. a ton, the yellow will bring only 25s., and the globe turnip 18s.

4. *Manure.*—The kind of manure affects the quality and feeding properties of the turnip. According to the experiments of Mr Lawes,* it appears that where a field is in a condition to produce an average crop of turnips, the proportion of nitrogen in the crop—that is, of albumen and other protein compounds, which are very nutritive—may be increased by the application of animal or other manures containing nitrogen—such as pigeons' dung, guano, woollen rags, rape cake, the salts of ammonia, nitrate of soda, &c. Mr Lawes states, that by the use of such manures the proportion of this valuable ingredient, compared with what is contained in turnips raised by farm-yard manure, may be doubled. This result has, to a certain extent, been confirmed by the more recent analyses of Scotch turnips, published by Dr Anderson. †

It is desirable, however, that the results of experiments in the laboratory, as to the composition of the crop, should be tested by after experiments with the same turnips in the actual feeding of cattle. Such experiments are difficult of execution, and require much care, but they are necessary to the attainment of results on which the practical man can be requested confidently to rely.

* *Journal of the Royal Agricultural Society of England*, viii. 494.

† *Quarterly Journal of Agriculture* for January 1852, pp. 221-223.

SECTION IV.—COMPOSITION OF THE CABBAGE, CAULIFLOWER, MUSHROOM, TURNIP-TOP, HAY, STRAW, AND THE LEAVES OF TREES.

1. The *Cabbage* is one of the most nutritious crops we grow. Like the turnip, it contains a large proportion of water—about 89 per cent; but the dry matter of the cabbage is much more rich in protein or tissue-forming compounds than that of the turnip. It consists very nearly of—

Starch, sugar, &c.,	46
Protein compounds, (albumen, &c.)	30 to 35
Oil or fat,	3
Cellular fibre,	9
Saline or mineral matter,	12 to 18
	100

The value of the cabbage in feeding—especially for milch cows—and its exhausting effect upon the soil, are not therefore to be wondered at.

2. The *Cauliflower* is still more nutritious than the cabbage leaf. It contains about 64 per cent of protein compounds. In this respect it approaches nearer to animal food than any vegetable we grow, of which the composition has yet been examined.

3. The *Mushroom* comes nearest to the cauliflower in this respect. It contains about 56 per cent of protein compounds; and though by some found to be indigestible, its nutritive qualities are very generally admitted.

4. The *Turnip-top*, though apt to scour cattle if given too freely, is generally as nutritive as the bulb. It contains as large a per-centage both of protein compounds and of phosphates, especially when young. The young sprouts which turnips, left in the field, throw out in spring, resemble cabbage very much, and are very nutri-

tious. Hence the reason why turnips which have thrown out large leaves in spring are generally found less valuable in feeding.

The composition of the turnip-top indicates the cause both of its great value as a manure when left upon the land, and why it forms a very appropriate food for the milch cow and the growing calf.

5. *Hay and Straw* are distinguished by the large proportion of cellular or woody fibre, in an indigestible state, which they contain. Good hay, however, contains also from 6 to 9 per cent of protein compounds, and clover hay even as much as 12 per cent; so that, in muscle-forming matter, hay is nearly as rich as our English wheat. The straw of our white-corn plants contains only 3 or 4 per cent of these compounds. Pea and bean straw are more nutritious—good pea straw approaching in this respect to the best clover hay.

6. The *Leaves of Trees* are often very nutritious; and did they not frequently contain substances which render them unpalatable or unwholesome when eaten, they might be very extensively employed as food for cattle. The dry tea-leaf contains about 25 per cent of protein compounds, chiefly albumen, and would prove as nutritious in this respect as an equal weight of beans or peas, were it the fashion in Europe to eat it. The tobacco leaf contains about 23 per cent. The elephant—the largest of existing quadrupeds—lives much upon leaves in its native forests; and in some Alpine countries, the annual harvest of dried leaves forms an important part of the winter's provision for the domesticated cattle.* (See p. 348.)

* "For several miles, when crossing the high Alps of Savoy, we observed the peasants stripping the mountain ash trees of all their leaves, for their cattle during the winter."—WELD'S *Tour in Auvergne and Piedmont.*—[Were these leaves gathered for food or for litter?]

It is not surprising, therefore, that leaves should form a valuable manure, or that poor land should be permanently improved by planting it with trees, (p. 176.)

SECTION V.—OF THE COMPOSITION OF FRUITS, AND THE EFFECT OF SOIL UPON THEIR QUALITY AND FLAVOUR.

To fruits it is necessary to do little more than allude in the present work.* They contain from 70 to 90 per cent of water—the quantity diminishing as the fruit ripens. In the fleshy fruits—plums, peaches, &c.—when ripe, the water forms about 75 per cent; in apples, pears, and gooseberries, a little more than 80 per cent of the whole weight. The dry matter contains chiefly sugar and pectic acid, with a considerable proportion of protein compounds and of soluble phosphates. Fruits are therefore fitted to nourish as well as to refresh. The dried gooseberry contains about 9 per cent of protein compounds. The acidity of our usually cultivated fruits is due to the presence of variable quantities of malic and citric acids.

In cider, perry, and wine countries, the nutritive qualities of the apple, pear, and grape are seen in the use of the refuse of the mills in feeding pigs or other animals; or where it is not used up in this way, these qualities are equally shown by the profitable employment of the refuse as a manure.

Fruits of all kinds, like our corn and root crops, are affected in flavour and quality by the soil on which they grow. In the Norman orchard, the *gout de terrain* is a recognised quality both in the apple and in the cider. The extended apple and peach culture of North America has led to similar observations; and the peculiar qualities possessed by the wines of neighbouring vineyards are

* For fuller information, see the Author's published *Lectures*.

familiar everywhere. There are only three farms situated on the side of a hill which produce the famous Constantia wine. The same grape has been tried in various parts of the Cape colony without success. Even a mile from the hill the wine is of a very inferior description. In Europe, on the banks of the Rhine, the Johannisberg is equally well known for the unique qualities of its celebrated wine.

SECTION VI.—INFLUENCE OF THE TIME OF CUTTING ON THE QUANTITY AND QUALITY OF THE PRODUCE OF HAY AND CORN.

1. *Hay.*—The period at which hay is cut, or corn reaped, materially affects the quantity (by weight) and the quality of the produce. It is commonly known that when radishes are left too long in the ground they become hard and woody—that the soft turnipy stem of the young cabbage undergoes a similar change as the plant grows old—and that the artichoke becomes tough and uneatable if left too long uncut. The same natural change goes on in the grasses which are cut for hay.

In the blades and stems of the young grasses there is much sugar and starch, which, as they grow up, are gradually changed into woody or cellular fibre, (p. 44.) The more completely the latter change is effected—that is, the riper the stem of the plant becomes—the less sugar and starch, both readily soluble substances, its various parts contain. And though it has been ascertained that cellular fibre is not wholly indigestible, but that the cow, for example, can appropriate a portion of it for food as it passes through her stomach—yet the reader will readily imagine that those parts of the food which dissolve most easily, are also likely, other things being equal, to be most nourishing to the animal.

It is ascertained, also, that the weight of the hay or of the straw we reap, is actually less when it is allowed to become fully ripe; and therefore, by cutting soon after the plant has attained its greatest height, a larger quantity, as well as a better quality of hay, will be obtained, while the land also will be less exhausted.

2. *Straw.*—The same remarks apply to crops of corn—both to the straw and to the grain they yield. The *rawer* the crop is cut, the heavier and more nourishing the straw. Within three weeks of being fully ripe, the straw begins to diminish in weight; and the longer it remains uncut after that time, the lighter it becomes, and the less nourishing.

3. *Grain.*—On the other hand, the ear, which is sweet and milky a month before it is ripe, gradually consolidates—the sugar changing into starch, and the milk thickening into the gluten and albumen of the flour. As soon as this change is nearly completed, or about a fortnight before it is ripe, the grain of wheat contains the largest proportion of starch and gluten. If reaped at this time, the bushel will weigh most, and will yield the largest quantity of fine flour and the least bran.

At this period the grain has a thin skin, and hence the small quantity of bran. But if the crop be still left uncut, the next natural step in the ripening process is, to cover the grain with a better protection—a thicker skin. A portion of the starch of the grain is changed into woody fibre—precisely as in the ripening of hay, of the soft shoots of the dog-rose, and of the roots of the common radish. By this change, therefore, the quantity of starch is lessened and the weight of husk increased; hence the diminished yield of flour, and the increased produce of bran.

Theory and experience, therefore, indicate about a

fortnight before it is fully ripe as the most proper time for cutting *wheat*. The skin is then thinner and whiter, the grain fuller, the bushel heavier, the yield of flour greater, its colour fairer, and the quantity of bran less; while, at the same time, the straw is heavier, and contains more soluble matter than when it is left uncut until it is considered to be fully ripe.

In regard to *oats*, it is said that the superiority of Ayrshire oatmeal is partly owing to the grain being cut rather *glazy*, (that is, with a shade of green upon it,) and the straw is confessedly less nourishing for cattle when the crop is allowed to stand till it is dead ripe. Early cut oats, also, are heavier per bushel, fairer to the eye, and usually sell for more money. A week before full ripeness, however, is the utmost that is recommended in the case of oats, the distance of the top and bottom grains upon the stalk preventing the whole from becoming so uniformly ripe as in the ear of wheat.

Barley cut in the *striped* state is also thinner in the skin, sprouts quicker and more vigorously, and is therefore preferred by the maltsters. It is also fairer to the eye, and generally brings a higher price in the market.

SECTION VII.—OF THE RELATIVE QUANTITIES OF STARCH AND GLUTEN IN OUR USUALLY CULTIVATED CROPS.

In addition to the details already given in regard to the composition of the several kinds of grain and roots usually cultivated in this country, it may be useful to exhibit, in a tabular form, the relative proportions of starch and gluten contained in each. The following numbers cannot be considered as precisely accurate, yet they represent pretty nearly the average quantities of these two substances contained in 100 lb. of our common

crops in the state of dryness, &c., in which they are usually sent to market:—

	Starch, gum, and sugar.	Gluten, albumen, &c.
Wheat, (flour,)	55	10 to 19
Bran of wheat,	—	16
Barley,	60	12 to 15
Oats, (without husk,)	60	14 to 19
Rye,	60	10 to 15
Indian corn (maize,)	70	12
Bran of do.	—	13
Rice,	75	7
Beans, peas, vetches, and lentils,	40 to 50	24 to 28
Linseed,	40	24
Potatoes,	18	2
Do. sliced and dried,	72	8
Turnips, carrots, and mangold-wurtzel,	9 to 11	1½ to 2
Do. sliced and dried,	90	12 to 16
Cabbage,	—	30 to 35

These numbers are somewhat open to correction. Indeed, if the reader recollects what has been stated in the previous sections, in regard to the variable quality of the different crops we raise, he will understand that the numbers contained in *all* tables such as this are to be regarded only as approximations to the truth.

SECTION VIII.—OF THE QUANTITY OF OIL OR FAT IN GRAIN, ROOT, AND HAY CROPS.

It is generally known that linseed, rape-seed, turnip-seed, hemp-seed, poppy-seed, and the seeds of many other plants, abound so much in oil, that it can be squeezed out by strong pressure, as is done in the mills of the oil manufacturers. The kernels of some nuts also, as those of the walnut, the hazel, and the beech, contain much oil; and even some trees, as certain species of the palm, yield it in large quantities.

It has only recently been discovered, however, that all our cultivated grains contain an appreciable quantity of

oil or fatty matter—that it is present also in our root crops, and that even in straw and hay it exists in sensible proportion.

Soil, climate, mode of culture, manure, and the variety of the plant we grow, all affect the proportion of oil which its seeds, stems, or roots contain. To extract this oil we have only to reduce the part of the plant into minute fragments, to boil these in ether, filter the solution, and afterwards distil off the ether, when the oil or fat will remain behind. It is usually more or less of a yellow colour, and when heated, not unfrequently emits an odour peculiar to the plant. Thus the oil from the oat emits, when heated, the well-known odour of burned oatmeal.

The proportion of oil contained in 100 lb. of some of our more commonly cultivated plants is as follows:—

Wheat flour (fine),	2 to 4 lb.
Bran of wheat,	3 to 5 lb.
Barley,	2 to 3 lb.
Oats,	5 to 8 lb.
Indian corn,	5 to 9 lb.
Linseed,	30 to 35 lb.
Rape and turnip seeds,	40 lb.
Potatoes, turnips, and cabbage,	½ lb.
Wheat straw,	2 to 3½ lb.
Oat straw,	4 lb.
Meadow hay,	2 to 5 lb.
Clover hay,	3 to 5 lb.

The quantity of fat varies, as this table shows, in the same kind of food. These variations are caused by differences in the soil, manure, climate, season, &c. In most seeds, however, the largest proportion of fat resides in the exterior part, near to or actually in the husk or bran. Hence the bran of wheat generally contains much more oily matter than the fine flour. Thus in two varieties of wheat, the fine flour from which contained only 1½, the bran contained from 3½ to 5 per cent of fat.

To this large quantity of oil, bran owes part of its

value in feeding pigs, as we shall see more clearly when, in a subsequent chapter, we come to consider the important part which this fatty matter performs in the artificial rearing and fattening of stock.

SECTION IX.—ON THE ABSOLUTE QUANTITY OF FOOD YIELDED BY AN ACRE OF LAND UNDER DIFFERENT CROPS.

The quantity of food capable of yielding nourishment to man, which can be obtained from an acre of land of average quality, depends very much upon the kind of crop we raise.

In the seeds of corn, when fully ripe, little sugar or gum is generally present; and it is chiefly by the amount of starch and gluten* they contain, that their nutritive power is to be estimated. In bulbs, such as the turnip and potato, sugar and gum are almost always present in considerable quantity in the state in which these roots are consumed, and this is especially the case with the turnip. These substances, therefore, must be included among the nutritive ingredients of such kinds of food.

If we suppose an acre of land to yield the following quantities of the usually cultivated crops, namely—

Of wheat,	25	bushels,	or 1500 lb.
Of barley,	35	...	or 1800 ...
Of oats,	50	...	or 2100 ...
Of pease,	25	...	or 1600 ...
Of beans,	25	...	or 1600 ...
Of Indian corn,	30	...	or 1800 ...
Of potatoes,	12	tons,	or 27000 ...
Of turnips,	30	...	or 67000 ...
Of wheat straw,	1⅓	...	or 3000 ...
Of meadow hay,	1½	...	or 3400 ...
Of clover hay,	2	...	or 4500 ...
Of cabbage,	20	...	or 45000 ...

* Including under gluten the albumen, avenin, legumin, and casein—all the varieties of protein compounds, in short, which are contained in grain. (See p. 50.)

The weight of dry starch, sugar, and gum—of gluten, albumen, casein, &c.—of oil or fat—and of saline matter, reaped in each crop, will be represented very nearly by the following numbers:—

	Husk or woody fibre.	Starch, sugar, &c.	Gluten, albumen, &c.	Oil or fat.	Saline matter.
Wheat, .	225	825 lb.	180 lb.	45	30
Barley, .	270	1080	230	50	50
Oats, .	420	1050	300	100	75
Pease, .	130	800	380	34	48
Beans, .	160	640	420	40	50
Indian corn,	100	1260	220	130	30
Potatoes, .	1080	4800	540	45	240
Turnips, .	1340	6000	1000	200	450
Wheat straw,	1500	900	40	80	150
Meadow hay	1020	1360	240	120	220
Clover hay,	1120	1800	420	200	400
Cabbage,	430	2300	1300	130	600

1. If it be granted that the quantities above stated are fair average returns of the different kinds of produce from the same quality of land—that the acre, for example, which, in our climate, produces 25 bushels of wheat, or 30 of Indian corn, will also produce 50 bushels of oats, or 12 tons of potatoes, or 30 of turnips, and so on*—then it appears that the land which, by cropping with wheat, would yield a given weight of *starch*, gum, and sugar, would, when cropped with barley or oats, yield one-fourth more of these substances—with potatoes about four times as much—and with turnips eight times the same quantity. In other words, the piece of ground which, when sown with wheat, will maintain one man,

* These are not by any means to be regarded as universally equivalent crops. Even in our country, local climate modifies very much the relative quantities of the same crops obtained in different localities. Thus, in the southern part of Wigtonshire, 30 tons of Swedes, 20 tons of mangold, and 20 tons of white carrots per acre are equivalent crops, while in Berkshire it is as easy to grow 30 tons of mangold as 20 tons of Swedes per acre. See *Journal of the Royal Agricultural Society*, vol. xiii. part i.

would support one and a quarter if sown with barley or oats, four with potatoes, and eight with turnips—*in so far as the nutritive power of these crops depends upon the starch, sugar, and gum they contain.*

2. Again, if we compare the relative quantities of gluten, &c., in the several crops, we see that wheat, barley, and Indian corn yield, from the same breadth of land, nearly equal quantities of this kind of nourishment—oats one-half more, peas and beans upwards of twice, potatoes upwards of thrice, turnips upwards of four times, and *cabbage six times as much as wheat or Indian corn.*

On whichever of these two substances, then—the starch or the gluten—we consider the nutritive property of the above kinds of food to depend, it appears that the turnip is on the whole the most nutritive crop we can raise. It is by no means the most nutritive, weight for weight; but the largeness of the crop—here taken at 30 tons—affords us from the same field a much greater weight of food than can be reaped in the form of any of the other crops above mentioned.

If, again, we look to the gluten alone, none of our crops can compete with the cabbage, even supposing the crop not to exceed 20 tons an acre.

3. Further, the oil or fat they contain is not without its value in relation to the nutritive, and especially to the fattening properties of the different crops. In this respect also the turnip would appear to be superior to most of the other usual forms of vegetable produce. Clover hay and Indian corn can alone be compared with it.

In these two facts the practical farmer will see the peculiar adaptation of the turnip husbandry to the rearing and fattening of stock. Could the turnip be rendered an agreeable article of general human consumption, the produce of the land might be made to sustain a much

larger population than under any of the other kinds of cropping above alluded to. Attempts have been made to grind them, and convert them into meal, as is done with the potato; but the cost of manufacturing, and the disagreeable taste of the meal, have hitherto stood in the way of a successful prosecution of this branch of rural industry.

The relative nourishing powers of different vegetable substances, or their value for food, is supposed by some to depend entirely upon the relative proportions of gluten, &c. they contain. According to this view, the pea and the bean are much more nourishing, weight for weight, than wheat, or any other grain, since 100 lb. of beans would afford as much gluten to an animal as 230 lb. of wheaten flour or Indian corn, or as 130 lb. of oats or 200 lb. of rye; and, in like manner, an acre of cabbage would support both more people and more stock even than an acre of turnips. This opinion, however, is not altogether correct.

But we shall be able to form a better judgment in regard to the relative value of the starch and gluten, as well as to understand the importance of the *saline* matter of the food, when we come in a succeeding chapter to consider the several purposes which the food is destined to serve in the animal economy—what different substances the animal must derive from its food in order to nourish its growing body, to maintain its existing condition when full grown, or to admit of a healthy increase in its bulk.

CHAPTER XXIII.

Of milk and its products.—The properties and composition of milk.—Influence of breed, constitution, food, soil, &c., on its quantity and quality.—Adulteration of milk.—Composition of cream.—Churning.—Quality, composition, preservation, and colouring of butter.—Theory of the action of rennet.—Manufacture, quality, and varieties of cheese.

Of the indirect products of agriculture, milk, butter, and cheese are among the most important. They are in reality necessaries of life in all civilised countries, and are almost the sole productions of many agricultural districts. The various branches of dairy husbandry present also many interesting subjects of inquiry, on which modern chemistry throws much light.

SECTION I.—OF THE PROPERTIES AND COMPOSITION OF MILK.

Milk is a white opaque liquid, possessed of a slight but peculiar odour. It is heavier than water, usually in the proportion of 103 to 100. When left at rest for a number of hours, it separates into two portions—the *cream*, which rises to the surface, and the thinner creamless milk on which it floats. When the whole milk or the cream alone is agitated in a churn, the fatty part of the milk separates in the form of butter, while the milk itself, butter-milk, becomes slightly sour.

If left to itself for several days, milk sours and curdles; and if in this state it be placed upon a linen cloth, the

liquid part, or *whey*, will pass through, while the *curd* or cheesy part will remain on the cloth. The same effect is produced more rapidly by adding vinegar to the milk, lemon juice, muriatic acid (spirit of salt), or rennet. In Holland the milk is sometimes curdled for the manufacture of cheese by the addition of muriatic acid; but in most countries rennet is employed for this purpose. It is coagulated also by alcohol or any strong spirit, and hence, probably, the practice of adding a quantity of whisky or brandy to the rennet—as is done in many dairy districts.

When exposed to the air for a length of time, milk begins to putrefy and to ferment. It becomes disagreeable to the taste, emits an offensive smell, and ceases to be a wholesome article of food.

The milk of nearly all animals contains the same ingredients—cheesy matter or casein, butter, milk-sugar, and saline matter, but in different proportions. The best known varieties of milk consist nearly of

	Woman.	Cow.	Ass.	Goat.	Ewe.
Casein, (or curd,)	1.5	4.5	1.8	4.1	4.5
Butter,	3.6	3.1	0.1	3.3	4.2
Milk-sugar,	6.5	4.8	6.1	5.3	5.0
Saline matter,	0.5	0.6	0.3	0.6	0.7
Water,	87.9	87.0	91.7	86.7	85.6
	100	100	100	100	100

The milk of the ass appears from the above table to resemble woman's milk, in containing little cheesy matter and much sugar. It contains also much less butter than any of the other varieties above mentioned, and hence, probably, its peculiar fitness for invalids.

SECTION II.—INFLUENCE OF BREED, CONSTITUTION, FOOD, SOIL, &C., ON THE QUANTITY AND QUALITY OF THE MILK.

Both the quantity and the quality of milk are affected by a great variety of circumstances. Every dairy farmer knows that his cows give more milk at one season of the year than at another, and that the quality of the milk also—its richness in butter or in cheese—depends, among other conditions, upon the kind of food with which his cows are fed. It will be proper to advert to these circumstances a little in detail.

1. *The quantity and quality of the milk are affected by the breed.*—Small breeds generally give less milk, but of a richer quality. Good ordinary cows in this country yield an average produce of from 8 to 12 quarts a-day. Thus the dairy cows of

Devonshire give	12 quarts a-day,
Lancashire .	8 to 9 quarts a-day,
Cheshire and Ayrshire,	8 quarts a-day,

during ten months of the year; but crossed breeds are, in many districts, found more productive of milk than the pure stock of any of the native races.

The influence of breed both on the quantity and on the quality of the milk appears from the following comparative produce of milk and butter of one cow of each of four different breeds, in the height of the season, and when fed on the same pasture. The

	Milk.		Butter.
Holderness gave	29 quarts	and	38½ oz.
Alderney, .	19	...	25 oz.
Devon, .	17	...	28 oz.
Ayrshire, .	20	...	34 oz.

Not only was the quantity of milk very different in the four cows, but the produce of butter also—the Holderness, in the quantity both of milk and of butter, being greatly superior to all the other breeds.

The milk of the Holderness and of the Alderney breeds was equally *rich* in butter, as was the case also with that of the Devon and the Ayrshire, since 1 lb. of butter was yielded by

12	quarts of milk	from the	Holderness cow.
12	...	...	Alderney cow.
9¾	...	...	Devon cow.
9½	...	...	Ayrshire cow.

Some stocks of Jersey cows produce 1 lb. of butter from 8½ quarts of new milk, the year round, and at the same time consume less food than others.

The butter of the milk is often in great part derived directly from the fat of the food. Hence the value of food which, like Indian corn and linseed cake, is rich in oil. Hence, also, those animals which lay the smallest proportion of this fat upon their own bodies will be likely to give the largest proportion in their milk. Thus the Ayrshires and Alderneys, which are good milkers, are *narrow* across the shoulders, and *wiry and muscular* about the flanks. They give a rich milk, but rarely fatten well. The *short-horns*, on the contrary, are celebrated for their fattening tendency. They deposit more of the fat under their skin, and impart less of it to their milk. In both breeds, however, there are striking exceptions, because—

2. The *individual form and constitution of the cow* causes both the yield and the richness to vary much among animals of the same breed. Every dairy farmer knows that some Ayrshire, or Holderness, or Devon cows are better milkers than others. And even when they yield nearly the same quantity of milk, the richness or produce

in butter may be very unlike. Thus, four cows of the Ayrshire breed, fed on the same pasture, gave in the same week—the

	Milk.		Butter.
First, . . .	84 quarts which yielded		3½ lb.
Second and third, each,	86	... ...	5½ „
Fourth, . . .	88	... ...	7 „

so that the fourth, though it produced only four quarts more milk, gave twice as much butter as the first.

Individual cases of extraordinary productiveness occur now and then. Thus a Durham cow belonging to Mr Hewer of Charlton, Northampton, gave in the height of the season 8 imperial gallons of milk in a day, yielding 3 lb. of butter. A cow upon ordinary keep has been known also to produce as much as 350 lb. of butter in a year. The tendency to yield butter is no doubt constitutional, like the tendency to lay on fat.

3. The *kind of food* also exercises, as all cowfeeders know, much influence upon the quantity and upon the richness of the milk.* The Swedish turnip and the cabbage give a richer milk, the white globe turnip a larger quantity, while both varieties of turnips are said to cause a greater yield of milk when tops and bulbs are given together. Culpepper recommends the leaves of the black alder as a fodder for causing cattle to give much milk. (See p. 333.) Spurry is said to have a similar effect. When fed on grass and brewers' grains, the cow yields a larger quantity of milk; and when fed on malt dust, she drinks much and milks well.

It is believed, also, that cabbage and the leguminous plants, such as clover, tares, &c.—as well as the cultivated seeds of such plants, beans, peas, &c.—promote the production of cheese; while oilcake, oats, Indian corn, and

* Hence the Ayrshire adage, "*The cow gives the milk by the mou.*"

other kinds of food, which contain much oily matter, favour the yield of butter. The cakes left by oily seeds, linseed, poppy seed, dodder, sesamin, give a milk which contains more solid matter, and is richer both in butter and cheese. If the cake be not old or rancid, it does not impair when given in moderate quantities, but rather increases the flavour and pleasantness of the butter.

If the food contain little fat, the animal still produces butter. It has the power of changing the starch and sugar of its food into fat during the process of digestion. It even robs its own body of fat, becomes leaner, and thus yields more fat in the form of butter than it has eaten in its food. Where only part of a dairy of cows is kept for their butter, and the rest for cheese, the butter-milk from the former may be given to the latter, and thus the produce of cheese increased. In the State of New York, cows are said to yield 100 lb. more cheese in a year when the whey from their own milk is added to their daily food.

4. *The nature of the soil* also in which plants grow, and the manure by which they are raised, affects their influence upon the milk. It has been known from the most remote times, that when fed upon one pasture the cow will yield more butter, upon another more cheese. This difference must depend upon the soil. Again, it has been found by experiment, that vetches grown upon well-limed or marled land promote the production of cheese, while, after a manuring with wood-ashes, they increase the quantity of milk and of cream, (SPRENGEL.) In Cheshire the addition of bones has greatly increased the value of the grass, and the produce of milk and cheese ; while, as to the quality, it has been found in Leicester that the manuring of old pasture with good farm-yard manure, rendered the cheese for three years nearly unsaleable.

On this curious subject numerous experimental researches are still required.

5. The milk is affected also by *a variety of other circumstances.* Its quantity depends very much upon the distance from the time of calving, diminishing as the calf in the womb gets older. This is no doubt a natural adaptation to the wants of the calf, which, in a state of nature, gradually ceases to require support from its mother. A cow which, during the first fifty days after calving, yields 24 quarts of milk a-day, may yield no more than 6 quarts a-day after six months have elapsed.

The quality of the milk is better from cows that are in good condition and have already been two or three times in calf—it is richer in warm climates, in dry seasons, and when the cow is not too frequently milked. It is said to be richer when cows are kept constantly in the house and regularly fed—those which go at large in the pasture yielding more cheese. When a cow is allowed to go dry for two or three months before calving, it is believed to give more milk the following season. In autumn it is richer upon the whole, giving a less proportion of butter, but a greater of cheese (AITON,) while it becomes poorer in both when the cow is in calf. The first milk which comes from the udder is also poorer than that which is last drawn, the *strippings* or *stroakings*—and, lastly, the quality of the milk is very much affected by the treatment and moral state of the animal. Gentle treatment and a state of repose are favourable to the richness of the milk; while anything that frets, irritates, or harasses the animal, injures its quality. I need scarcely add that cleanliness and good ventilation in the cow and milk houses are essential to the good flavour of milk.

SECTION III.—OF THE ADULTERATION OF MILK.

Milk is almost everywhere more or less adulterated with water. In Paris and the neighbourhood, the cream is taken off, and the skimmed milk thickened with sugar and an emulsion of sweet almonds or hemp-seed, (RASPAIL.) Skim milk may also be thickened with magnesia, and by this means the thickness of cream may be given to new milk, while it will also be kept longer sweet. Common soda or pearl-ash is sometimes added to milk which has turned, to restore its sweet taste.

But the most singular adulteration of which I have heard is that of mixing up the skim milk with calf's and sheep's brains. This mixture renders it thick and rich, and causes a coating, apparently of cream, to rise to the surface, which it requires a nice chemical examination to distinguish from genuine cream.*

SECTION IV.—OF THE COMPOSITION OF CREAM AND THE CHURNING OF BUTTER.

1. *Cream.*—When milk is left at rest for a length of time, the fatty matter which floats in it in the form of minute globules, rises to the surface in the form of cream. The rapidity with which it thus rises to the surface depends upon the temperature to which it is exposed—being quicker in warm than in cold weather. Thus, for example, when milk is set aside it may be perfectly creamed in

* The method of examination is to treat the creamy matter with ether, and to boil what the ether takes up with water containing a little sulphuric acid. If the cream is not genuine, the acid solution will then give with lime or baryta traces of phosphoric acid.

Hours.			Degrees F.
36 when the temperature of the air is			50
24	...	...	55
18 to 20	...	...	68
10 to 12	...	...	77

while at the temperature of 34° to 37° F.,—a little higher than the freezing point of water,—milk may be kept for three weeks without thowing up any notable quantity of cream.

If the milk when new is placed in a hot basin, and covered over with another, the cream is thrown up more quickly, and a larger quantity of butter is obtained. Of course, the skimmed milk will be so much the poorer.

The cream thus thrown up contains the greater part of the fatty matter of the milk, mixed with a small proportion of curd and much water. Cream of good quality in this country, when skilfully churned, will yield about one-fourth of its weight of butter; or, one wine gallon of cream weighing 8¼ lb. will give nearly 2 lb. of butter.

2. *Churning.*—When milk or cream is agitated for a length of time, the fatty matter gradually separates from the milk, and collects in lumps of *butter*. There are several circumstances in connection with the churning to which it is of interest to attend.

a. In the churning of *cream* it is usual to allow the cream to stand in cool weather for several days, until it becomes distinctly sour. In this state the butter comes sooner, and more freely. The butter, when collected in lumps, is well beat and squeezed from the milk. In some places it is usual also to wash it in cold water as long as it renders the water milky; in other places the remaining milk is separated by repeated squeezings, and by drying with a clean cloth.

b. Clouted cream may be churned with advantage in the sweet state—the butter separating from it with great

ease. Colonel le Couteur states that, in Jersey, *it is usual to make ten pounds of butter in five minutes* from the clouted cream of the Jersey or Alderney cow. Clouted cream is obtained by gradually heating the milk in deep pans, almost to boiling, but so as never to break the skin or *clout* that forms on the surface. The cream is said to be more completely separated by this process than by any other, and a larger quantity of butter to be obtained from the milk.

c. The whole milk may also be churned, after being allowed to stand till it has attained the proper degree of sourness, which is indicated by the formation of a stiff brat on the surface, *which has become uneven*. This method is more laborious, requiring more time than when the cream only is used; but it has the advantage, as many practical men have found, of yielding five per cent more butter from the same quantity of milk, and of a quality which never varies in winter or in summer. It also requires no greater precautions or more trouble to be taken in warm than in cold weather.

d. Temperature.—This latter advantage is derived from the circumstance, that the temperature at which the whole milk ought to be churned is higher than that of the air in our climate, throughout nearly the whole course of the year. The temperature at which milk can be churned most economically is about 65° F., a degree of heat which the air seldom attains in our warmest summer mornings. The dairy-maid has simply to add hot water enough to the milk to raise it to 65° F., and to repeat this every morning of the year, if she churns so often. On the other hand, the temperature of cream, when churned, should not be higher than from 53° to 55° F., a temperature beyond which the air often rises. It becomes necessary therefore, in summer, to cool the milk-room in which the

cream is churned, and, by churning early in the morning, to endeavour to keep the cream down to the proper temperature.

Thus, in churning cream, the task of the dairy-maid is a more difficult one. In winter, she must add hot water to bring the temperature up to 55°, and in summer must apply cold, to keep it down. In this she sometimes fails, and on these occasions the quality of the butter suffers.

e. The time required for churning the whole milk in the ordinary churn is from three to four hours, while the cream alone can be churned in about an hour and a half. A churn, however, has lately been introduced which churns both milk and cream in a much shorter period of time. It is made of tin, is of a barrel-shape, and is placed in a trough of water, which is heated to the temperature the milk or cream ought to be brought to. In this churn the butter was extracted from *cream*, at the temperature of

56° F. in 60 minutes, . .	Butter was harder, but no better than the following.
58° F. in 10 to 20 minutes, .	Butter excellent.
60° F. in 5 to 7 minutes, .	Soft *at first*, but of good colour and quality.

The whole milk in this churn gave the butter in one hour to one hour and a half. Mr Burnett of Gadgirth informs me, that he obtains in this churn a larger quantity of butter from the cream than from the whole milk. Thus, from 508 quarts of milk—the produce of five cows in one week of July (1843)—he obtained, on churning the whole milk, 36 lb. 11 oz. The cream, on the other hand, yielded by an equal quantity of milk drawn from the same cows during another week, gave him 37 lb. 4 oz., being a difference of 9 ounces, or about 3 per cent in

favour of the cream, which is contrary to general experience with the ordinary churn, as stated in the previous page.

Other persons who have tried this churn have not been so successful in the use of it as Mr Burnett. Where they have obtained the butter much sooner than usual, they have found reason to complain of its quality. Perhaps in these cases the churn has not been skilfully used, or something may depend upon the quality of the milk—since the cream from the milk of some cows is said in the ordinary churn *always* to come to butter in ten minutes or less.

The *air churn*—a still more recent invention—which agitates the milk, by forcing a current of air through it, is said to bring the butter in the still shorter period of four minutes.

f. The largest quantity of butter from a given weight of the same food, and the richest milk, are yielded by the milk of the smaller races. The small Alderney, or Jersey, West Highland, and Kerry cows, give a richer milk even than the small Ayrshire. But the small Shetlander is said to surpass them all. These breeds are all hardy, and will pick up a subsistence from pastures on which other breeds would starve.

The quantity of butter yielded by different cows in the same yard, and eating the same food, is sometimes very different. Some will yield only 3 or 4 lb. a-week, while more will give 8 or 9 lb., and a few 15 lb. a-week. As a rare instance, I may mention that a cow has been known in Lancashire to yield upwards of 22 lb. in seven days.

SECTION V.—OF THE QUALITY, COMPOSITION, PRESERVATION, AND COLOURING OF BUTTER.

1. *The quality of butter* varies with numerous circumstances. The kind of natural pasture, or of artificial food, upon which the cow is fed, the season of the year, the breed, the individual constitution and state of health of the animal, the mode of churning, the cleanliness of the cow and milk houses, &c., all more or less affect the quality of the butter.

But from the same cow, fed on the same food, and in the same circumstances, a richer butter, and of a finer and higher flavour, will be obtained by churning the last drawn portions of the milk. So the first cream that rises gives the finest flavoured butter,—while any cream or milk will give a butter of better quality if it be properly soured before it is churned, and be then churned slowly and at a low temperature.

2. *The composition of butter.*—Butter, as it is usually brought to the market, contains more or less of all the ingredients of milk. It consists, however, essentially of the fat of milk, intimately mixed with about one-eighth of its weight of water, and a small quantity of casein or curd, of saline matter, and of the sugar of milk. The quantity of casein (cheesy matter or curd) seldom amounts to one per cent of the whole weight of the butter.

If the butter be melted in hot water several times, shaken with renewed portions of water as long as they become milky, and left then to repose, it will collect on the surface in the form of a fluid yellow oil, which will concrete or harden as it cools. If when cold it be put into a linen bag, and be submitted to strong pressure in

a hydraulic or other press, at the temperature of 60° F., a slightly yellow transparent oil will flow out, and a solid white fat will remain behind in the linen cloth. The solid fat is known by the name of *margarine, and is identical with the solid fat of the human body,* with that of the goose, and with that which causes the thickness of olive oil when exposed to the cold. It is very similar also to the solid fat of palm oil. The liquid or *butter oil* is a peculiar kind of fat not hitherto discovered in any other substance.

The proportion of these two kinds of fat in butter varies considerably, and hence the different degrees of hardness which different samples of butter present. The solid fat is said to abound more in winter, the liquid fat in summer. Winter and summer samples of butter manufactured in the Vosges were found to contain per cent respectively of

	Summer.	Winter.
Solid fat or margarine, . .	40	65
Liquid fat or butter oil, . .	60	35
	100	100

These proportions, however, will be found to vary more or less in almost every sample of butter we examine.

In Jersey, the drainings of the curd in rich-cheese making give a butter which is inferior for eating with bread, but very superior for pastry. It is peculiarly hard, and fitted for such use in hot weather. It probably contains more of the solid fat of butter.

3. *The preservation of butter.*—Fresh butter cannot be kept for any length of time in our climate without becoming rancid. The fats themselves undergo a change; and the same is the case with the small quantity of milk sugar which the butter contains. The main cause of this change is the casein or curd which is usually left in the

butter. The proportion of this cheesy matter I have found in two samples of fresh butter to vary from one-half to three-fourths of a per cent,—or from half a pound to three-quarters of a pound in 100 pounds of butter; and yet this small quantity is sufficient, if the butter be exposed to the air, to induce those chemical decompositions to which the disagreeable smell and taste of rancid butter are owing. The butter made in the pure air of the Alpine valleys of Piedmont and Switzerland, after a complete expression of the milk, is said to be "preserved sweet, or at least fit for use, through the whole season, without any admixture of salt." By melting and skimming the butter also, and then pouring it hot into a jar, it is in Switzerland preserved without salt. In this latter state it is called boiled butter, (*beurre cuit,*) and is chiefly used for cookery.*

I do not enter here into the theory of the action of this casein, nor into an explanation of the nature of the chemical changes themselves.† It is sufficient to state, that this evil action of the cheesy matter may be entirely prevented.

a. By salting immediately after the butter is made, and before the cheesy matter has had time to become altered by exposure to the air.

b. By taking care that any water which may remain in or around the butter be always kept perfectly saturated with salt.

c. By carefully excluding the air from the casks or other vessels in which the butter is packed.

So long as the cheesy matter is kept from the air, and in a saturated solution of salt, it will neither undergo

* *Physician's Holiday*, by Dr FORBES, p. 336.

† The reader will find these fully explained in the Author's published *Lectures on Agricultural Chemistry and Geology*, 2d edit., p. 976.

any rapid alteration itself, nor will it soon induce any offensive alteration in the butter.

About half a pound of salt is used to 12 or 14 lb. of butter; but when salted for exportation, or for the use of the navy, one pound of salt is added to 10 or 12 of butter. Though many wash their butter, it is a rule with others *never to wash it or dip it into water when intended to be salted*, but to work it with cool hands till the butter milk is thoroughly squeezed out, and then to proceed with the salting, Theoretically, I should consider this latter as the better plan, since it exposes the cheesy matter less to the air, and consequently to less risk of incipient decomposition.

Some fancy they cure their butter better by dissolving the salt in the cream before churning, while many consider its preservation and good quality to depend much upon the quality of the salt that is employed.

Some prefer, instead of salt alone, to make use of a mixture of one part of sugar, one of nitre, and two of salt; and some who use an impure salt, consider the butter to be improved by washing it in a saturated solution of salt.

It is said that rancid butter may be rendered sweet by churning it with fresh sweet milk, in the proportion of six pounds of butter to the gallon.

4. *Colouring butter.*—Butter is sometimes coloured, and the juice of scraped carrots is not unfrequently employed for the purpose.

SECTION VI.—OF THE SOURING OF MILK, OF MILK-SUGAR, AND OF THE ACID OF MILK.

1. When milk is left to itself for a sufficient length of time, it becomes sour and curdles. This takes place

sooner in warm weather, and in vessels which have not been cleaned with sufficient care.

Why does milk thus become sour?

a. *Sugar of milk.*—I have already stated that milk contains a quantity of a peculiar kind of sugar, found only in milk, to which, therefore, the name of *milk-sugar* is given. It differs from common cane sugar in being harder, less sweet, and much less soluble in water. *Of this sugar, milk contains generally a larger proportion than it does of either fat or curd,* (p. 345.) A gallon of milk, therefore, would yield a greater weight of sugar than it does of either butter or cheese. In this country, the sugar is usually neglected. In our cheese districts, it is given to the pigs and sometimes to the cows in the whey with which they are fed. In Switzerland and elsewhere, it is extracted as a profitable article of commerce.

b. *Acid of milk.*—When milk becomes sour, a peculiar acid is formed in it, to which, from its having been first observed in milk, the name of lactic acid, or acid of milk, has been given. To this acid the sourness of milk is owing. The same acid is produced when crushed wheat—as in the manufacture of starch from wheat—wheaten flour, oatmeal, pease-meal, &c., or when cabbage and other green vegetables are mixed with water, and allowed to become sour. It exists also in small quantity in the acorn, (p. 320.)

c. *But how is the acid produced?*—As the acid of milk increases in quantity, the sugar of milk diminishes. The acid, therefore, is formed from or at the expense of the sugar. There is no fermentation, and therefore no loss of matter: the sugar is merely transformed into the acid, and by a process the outline of which it is very easy to understand. Like cane sugar, grape sugar, and gum, (p. 46,) both may be represented by, or may be supposed

to consist of, carbon and water, and in the same proportions. Thus,—

	Carbon.		Water.
Sugar of milk consists of . .	6	and	6
Acid of milk, (*lactic acid*,) . .	6	and	6

The same particles of matter, therefore, which compose the sugar, are made to assume a new arrangement, and, instead of a sweet sugar, to form a sour acid. In the interior of the milk, nature takes down and builds up its materials at her pleasure,—using the same molecules to form now this and now that kind of substance—as the child plays with its wooden bricks, erecting a hut or a temple with the materials of a ruined palace or a fallen bridge. So nature seems to play with her materials,—working up all, wasting none,—yet so skilful in all her operations as to excite our wonder, so secret as not unfrequently to escape our observation, and so quick as often to show that she has been working, only by the striking effects she has produced. To the simple peasant and to the instructed philosopher, it is equally a matter of wonder, and almost equally unintelligible, that the same number of material particles arranged in one way should affect the organs of taste with the sweetness of sugar, in another with the sourness of lactic acid.

SECTION VII.—OF THE CURDLING OF MILK, OF CASEIN, AND OF THE ACTION OF RENNET.

As milk becomes sour, it also thickens or curdles. If it be then slightly heated, the curd runs together more or less, and separates from the whey. If the whole be now thrown upon a linen cloth and gently pressed, the clear whey will run through and the curd will remain on the cloth. This curd, when salted, pressed, and dried, forms

the cheese which we consume so extensively as an article of food.

In consequence of what chemical change does this separation of the curd take place?

1. It is to be borne in mind, that this curdling does not take place *naturally* till the milk has become sour. The acid of the milk, therefore—the lactic acid—has some connection with the separation of the curd. It is, in fact, the cause of the curdling.

2. But, in order to understand how this is, we must turn for a moment to the properties of the curd itself. Chemically pure curd or casein is a protein compound, which contains less sulphur than albumen does, and no phosphorus, (p. 49.)

a. When the curd of milk is separated carefully from the whey, it may be washed or even boiled in water, without being sensibly lessened in quantity. *Pure curd is nearly insoluble in pure water.*

b. But if a little soda be added to the water in which the curd is heated, it will dissolve and disappear. *Pure curd is soluble in a solution of soda.*

c. If to the solution of the curd in soda and water a quantity of the *acid of milk* be added, this acid will combine with the whole of the soda—will take it from the curd, which will thus be again separated in an insoluble state. *The curd is insoluble in water, rendered sour by the acid of milk.*

These facts explain very clearly the curdling of milk. As it comes from the cow, milk contains a quantity of soda *not combined with any acid*, by which soda the curd is believed to be held in solution. As the milk becomes sour, this soda combines with the lactic acid produced, and thus the curd becoming insoluble separates from the whey—or the milk thickens and curdles.

Now, the effect which is thus produced by the natural formation of lactic acid in the milk, may be brought about by the addition of any other acid to it—such as vinegar or spirit of salt. And, in fact, vinegar is used now, in some countries, and in ancient times was used more extensively, for curdling milk; while in some of the cheese districts of Holland, spirit of salt (muriatic acid) is said to be employed for the same purpose. Sulphuric acid has been also recommended, but has been found to give the cheese an unpleasant taste.

3. But in most dairy countries *rennet* is the substance used for the curdling of milk. What is rennet? and how does it act?

a. The stomach of the calf, of the kid, of the lamb, of the young pig, and even of the hare,* when covered with salt, or steeped for some time in water perfectly saturated with salt and then dried, forms the dried maw-skin or bag which is used for the preparation of rennet. If the dried skin of nine or ten months old be steeped in salt and water, a portion of its substance dissolves, and imparts to the water the property of coagulating milk. The water thus impregnated forms the rennet or yirning of the dairy-maid. In some districts it is usual to steep several skins at once, and to bottle the solution for after use—mixed with more or less brandy, whisky, or other spirit. In others, a portion of the dry skin, sufficient to make the quantity of rennet required, is cut off the night before, and steeped in water till the milk is ready in the morning. To this solution many dairy-maids add a quantity of strong spirit before putting it into the milk, which probably increases its coagulating power.

b. The rennet thus prepared coagulates more or less

* Three hares' stomachs are considered equal to one calf's.

readily, according to its strength. *On what principle does it act?*

If a piece of the fresh membrane of the calf's stomach or intestine, or even if a piece of fresh bladder, be exposed to the air for a short time, and be then immersed into a solution of milk-sugar, it gradually causes the sugar to disappear, and to change into lactic acid—the acid of milk. If the salted and dried membrane be employed instead, it will produce the same effect, only with greater rapidity.

But, by long exposure to the air in drying the surface, the salted membrane undergoes such a change that a portion of it becomes soluble in water, yet still retains or acquires, even in a higher degree, the property of changing milk-sugar into the acid of milk. It is this soluble portion which exists in the liquid rennet.

Now, the same effects which the membrane produces upon the sugar of milk alone, it produces also upon the sugar as it is contained naturally in the milk—in other words, *the rennet, when added to the warm milk, changes the sugar into the acid of milk.* This it effects more or less rapidly according to circumstances, and hence the different length of time which elapses in different dairies before the milk is fully thickened.

c. The addition of rennet, therefore, is only a more rapid way of making the milk sour, or of converting its sugar into lactic acid. The acid produced, as in the natural souring of milk, combines with the free soda, and renders the cheesy matter insoluble, which, in consequence, separates;—in other words, the milk curdles. The milk, it is true, does not become sensibly sour, because the production of acid in a great measure ceases as soon as the soda of the milk is fully saturated with the acid; and if any excess of acid be produced, it is taken up and absorbed or separated in and by the curd, so as to leave the

whey comparatively sweet. Even the rennet that is added is carried off by the curd, which is thus often injured in quality if too much rennet have been added, or if its smell or taste have been unpleasant. The sugar that remains in the whey is thus enabled to retain its sweetness—that is, to remain unchanged into acid—longer than it could have done had any excess of rennet remained in it after the separation of the curd.

The chemical change produced by rennet in curdling milk, therefore, is precisely the same as that which takes place when milk sours naturally. In both cases the lactic acid which is formed causes the milk to curdle.

SECTION VIII.—OF THE MANUFACTURE AND THE QUALITY OF CHEESE.

1. *The manufacture* of cheese is, generally speaking, conducted in the same manner in all countries. The milk is curdled by the addition of rennet, vinegar, muriatic acid (spirit of salt,) lemon juice, tartaric acid, cream of tartar, salt of sorrel,—by sour milk even, as in some parts of Switzerland,* or by the decoction of certain plants or flowers, as of those of the wild thistle, employed for the ewe cheeses of Tuscany.

The curd is then more or less carefully separated from the whey, tied up in a cloth, and exposed to gentle pressure. In general, the curd at this stage is broken small, and mixed with a due proportion of salt before it is allowed to consolidate and dry. For the thin cheeses of Gloucester and Somerset, however, this mode of salting is not adopted, the whole of the salt that is necessary being afterwards

* It is stated by old cheese-makers in Nottinghamshire, that churned milk added to cheese milk in the usual way, very much improves both the quality and taste of the cheese, and prevents it from rising after it is made.

rubbed in and made to penetrate through the exterior of the cheese.

After it is removed from the press, the cheese is rubbed over with salt, or is covered with a layer of it—at a later period is more or less frequently anointed with butter, is kept for a week or two in a rather warmish place, and is frequently turned. There are minute details to be attended to, where cheese of good quality is desired, with which the skilful and experienced dairy-maid is familiar, but upon which it is unnecessary here to dwell.

2. *The quality* of the cheese varies with a great variety of circumstances, partly natural and unavoidable, but partly also to be controlled by art.

a. Thus there are natural differences in the milk, arising from the kind of grass or other food on which the cows are fed, which necessarily occasion corresponding differences in the quality of the cheese made from it. The milk of different animals also gives cheese of unlike qualities. The ewe-milk cheeses of our own country, of Italy, and of France, and those of goat's milk made on Mount d'Or and elsewhere, are distinguished by qualities not possessed by cow's milk cheeses prepared exactly in the same way. The milk of the buffalo likewise gives a cheese of peculiar qualities, arising, as in the cases of the ewe and the goat, from some natural peculiarity in the composition of the milk itself.

b. But every dairy farmer knows that, from the same milk, cheeses of very different flavours, and of very unlike values in the market, may be made—that the mode of management has not much less to do with the peculiar quality of his dairy produce than the breed of cattle he uses, or the pasture on which his cows are fed. Very slight circumstances, indeed, affect the richness, flavour, and other valuable properties of his cheese.

Thus if the new milk, when the rennet is added, be warmer than 95° F., the curd is rendered hard and tough; if colder, it is soft, and difficult to free from the whey. If heated on the naked fire, as is often done, in an iron pot, the milk may, by a very slight inattention, become *fire-fanged*, and thus impart an unpleasant flavour to the cheese. If the curd stand long unbroken after the milk is fairly coagulated, it becomes hard and tough. If the rennet have an unpleasant flavour, or if too much be added, the flavour and keeping qualities of the cheese are affected. If acids are used instead of rennet, the properties of the cheese are altered. It is less rich if the whey be hastily and with much pressure squeezed out of the curd; or if the curd be minutely broken up and thoroughly mixed and stirred up with the whey, or *washed* by it, as is the custom in Norfolk—instead of being cut with a knife, so that the whey may flow slowly and gently out of it, as is done in Cheshire or Ayrshire—or instead of being placed unbroken upon the cloth, as in making Stilton cheese, so that the whey may drain and trickle out spontaneously, and may carry little of the fatty matter along with it. Some of the Cheshire dairymaids give their cheese a tendency to green mould, by setting or curdling their milk at a low temperature; and the inferiority of Dutch cheese is ascribed by some to the custom of soiling or feeding in the house, which affects the flavour of the cheese without injuring the health of the animal.

c. The kind of salt also which is used,* the way in

* The kind of salt preferred in the dairy districts of the west of Scotland is an impure variety from Saltcoats, which contains a notable quantity of the deliquescent salts, (chlorides of lime and magnesium.) These salts seem to keep the skin of the cheese moist, and to assist its *stoning*.

which the cheese is salted, the size of the cheese itself, and, above all, the mode in which it is cured, have very much influence upon its after qualities. Hence a fair share of natural ability, as well as long experience, are necessary in the superintendent of a large dairy establishment, when the best quality of cheese which the milk can yield is to be manufactured *uniformly*, and at every season of the year.

SECTION IX.—OF THE VARIETIES OF CHEESE.

The varieties of cheese which are manufactured are very numerous, but the greater proportion of these varieties owe their peculiar qualities to the mode of management which is followed in the districts or dairies from which they come. Natural varieties, however, arise under the same general management, and from the same milk, according to the state in which the milk is used. Thus we have—

a. Cream cheeses, which are made from cream alone, put into a cheese-vat, and allowed to curdle and drain of its own accord, and without pressure; or as in Italy, by heating the cream, and curdling with sour whey or with tartaric acid. These cheeses are too rich to be kept for any length of time.

b. Cream and milk cheeses, when the cream of the previous night's milking is mixed with the new milk of the morning, before the rennet is added. The English *Stilton* cheeses and the small soft *Brie* cheeses, so much esteemed in France, are made in this way.

c. Whole or full milk cheeses, which, like those of Gloucester, Wiltshire, Cheshire, Cheddar, and Dunlop, are made from the uncreamed milk. These cheeses, like the preceding, however, will be more or less rich according

to the way in which the curd is treated, and according as the milk is curdled while naturally warm, as in the best Ayrshire dairies, and in some parts of Holland—or is mixed, as in Cheshire, and in some Ayrshire dairies, with the milk and cream of the previous evening.

The large 60 to 120 lb. cheeses of Cheshire will not *stand*, will break and fall asunder, if all the cream is left in the milk. About one-tenth of the cream, therefore, is skimmed off and made into butter. About 20 lb. of butter a-week are thus made in a cheese dairy of 100 cows.

d. Half-milk cheeses, such as the single Gloucester, are made from the new milk of the morning, mixed with the skimmed milk of the evening before.

e. Skimmed-milk cheeses—which may either be made from the milk *once* skimmed, like the Dutch cheeses of Leyden, *twice* skimmed, like those of Friesland and Groningen, or skimmed for *three or four days* in succession, like the horny cheeses of Essex and Sussex, which often require the axe to break them, and are sometimes used for certain purposes in the arts.*

f. Whey cheeses made from the curd which is skimmed off the whey when it is heated over the fire. This is by no means a poor kind of cheese; and good imitations of Stilton are said to be sometimes made by mixture of this curd with that of the whole milk.

g. Butter-milk cheeses, made by simply straining the butter milk through a cloth, and then either gently heating the butter milk, which causes the curd to separate, or, as is sometimes done, by the addition of rennet. This kind of cheese is not unworthy of attention, as it is often richer than that made from milk only once skimmed.

* Suffolk cheese, which is locally known by the name of "Suffolk Bank," is so hard that "pigs grunt at it, dogs bark at it, but neither of them dare bite it."

Though it cannot, of course, have the richness, it is said to possess some of the other characteristic qualities of good Stilton cheese.

h. Vegetable cheeses are made by mixing vegtable substances with the curd. The green Wiltshire is coloured by a decoction of sage leaves, marigold, and parsley. I do not know if it is to this practice, or to one of actually mixing the sage leaves with the curd, that Gay alludes in the line—

> "Marbled with sage, the hardening cheese she pressed."

The Schabzieger cheese of Switzerland is a mixture of the curd obtained from the whey of skimmed milk, with one-twentieth of its weight of the dried leaves of the mellilot trefoil.*

i. The *Potato cheeses* of Saxony and Savoy consist of dry boiled potatoes mixed with a half or a third of their weight, or with any other proportion of the fresh curd, or simply with sour or with skimmed milk. The mixture is allowed to undergo a species of slight fermentation before it is made up into shapes. Such cheeses, when well cured, are said to form a very agreeable article of diet, and to be capable of being kept for a long period of time.†

* *Zieger* is the curd separated from whey either by a fresh addition of acid or in some other way.

† For further details in regard to milk and its products, the reader is referred to the Author's *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 928 to 1008.

CHAPTER XXIV.

On the feeding of animals.—Main visible functions of the living animal. —The food must supply the wants of respiration.—Nature, wants, and purposes of this function.—The daily waste of the muscular parts and tissues of the body.—Food necessary to repair it.—Saline and earthy matters contained in its several parts, and daily rejected by the body.—Waste or increase of fat supplied by the food.—Special waste in the perspiration.—Forms in which the solid matter of the tissues escapes in the urine of animals.—General balance of food and excretions.—Kind of food required, as indicated by the composition of the blood.—Importance of a mixed food.

THE food of plants we have seen to consist essentially of two kinds, the *organic* and the *inorganic*, both of which are equally necessary to the living vegetable—equally indispensable to its healthy growth. A glance at the purposes served by plants in the feeding of animals, not only confirms this view, but throws also additional light upon the *kind* of inorganic food which plants must be able to procure, in order that they may be fitted to fulfil their assigned purpose in the economy of nature.

SECTION I. — MAIN VISIBLE FUNCTIONS OF LIVING ANIMALS.

Man, and all domestic animals, may be supported, may even be fattened, upon vegetable food alone. Vegetables, therefore, must contain all the substances which are necessary to build up the several parts of animal bodies, and

to supply the waste attendant upon the performance of the necessary functions of animal life.

All living animals perform three main or leading functions necessary to the continuance of healthy life.

1°. They *breathe*, alternately inhaling and exhaling air by means of the lungs.

2°. They *digest*, dissolving the food in the stomach, and selecting from it the materials necessary to form blood.

3°. They *excrete*, rejecting in the solid excretions and the urine, or giving off from the skin and the lungs—

a. That part of the food which cannot be dissolved and made use of as it passes through the alimentary canal.

b. The materials derived from the decomposed tissues or parts of the body which are undergoing a constant waste.

To the wants of an animal performing these visible functions in a healthy and regular manner, the food must be adapted in kind and quantity. I shall briefly illustrate what these wants demand.

To the numerous minor and invisible functions performed within the several parts of the living body, it is unnecessary to advert in detail. I may have occasion incidentally to advert to one or two of the more interesting of these; but as a healthy blood contains all that is necessary to the discharge of these functions, it would only complicate our present inquiry to consider their several direct relations to the undigested food as it is introduced into the stomach.

SECTION II. — THE FOOD MUST SUPPLY THE WANTS OF RESPIRATION. — NATURE, WANTS, AND PURPOSES OF THIS FUNCTION.

While an animal lives it breathes. It alternately draws in and throws out atmospheric air by means of its lungs.

1. When this air enters, it contains about 2 gallons of carbonic acid in every 5000; when it escapes from the lungs it contains 2 gallons or upwards in every 100. The proportion is increased from 50 to 100 times. Much carbonic acid, therefore, is given off from the lungs of animals during breathing. In other words, living animals are continually throwing off carbon into the air, since carbonic acid contains about two-sevenths of its weight of solid carbon, (p. 21.)

A man of sedentary habits, or whose occupation requires little bodily exertion, may throw off in this way about 5 ounces of carbon in twenty-four hours—one who takes moderate exercise, about 8 ounces—and one who has to undergo violent bodily exertion, from 12 to 15 ounces. In our climate about one-fifth more is given off in summer than in winter.

If we take the mean quantity respired at 8 ounces, then, to supply this carbon alone, a man must eat 18 ounces of starch or sugar every day.* If he take it in the form of wheaten bread, he will require 1¾ lb. of bread; if in the form of potatoes, about 7½ lb. of raw potatoes to supply the carbon which escapes through his respiratory organs alone.

When the habits are sedentary, 5 lb. of potatoes may be sufficient; when violent and continued exercise is taken, 12 to 15 lb. may be too little. At the same time, it must be observed, that when the supply is less, either the quantity of carbon given off will be less also, or the deficiency will be supplied at the expense of the body itself, especially of its fatty part. In either case the strength will be impaired, and increased supplies of nourishing food will be required to recruit the exhausted frame.

* Since 12 lb. of starch contain about 5 lb. of carbon, (see p. 46.)

Other animals give off from their lungs quantities of carbon proportioned to their weights. A cow or a horse, eight or ten times the weight of a man, will give off 4 to 5 lb. of carbon. The quantity of food required to supply this carbon will be proportionably greater.

I have in the above calculations supposed that the whole of the carbon given off from the lungs is derived from the starch, sugar, or gum of the food. This view is the simplest, and most easily intelligible. It only requires us to suppose that in the system the starch is separated into carbon and water, of which, as we have seen, (p. 46,) it may be represented to consist; and that the former is given or burned off from the lungs in the form of carbonic acid. But many physiologists do not regard the process as being really so very simple. They consider that the carbon given off is partly derived from the gluten or flesh of the food, as well as from the starch or fat—in which case the quantity of starch or sugar in the food, as I have calculated it, need not be so large; and it is certain that where animals live on food which contains no starch or sugar, and but little fat, the gluten or fleshy fibre it contains must yield the carbon which is given off by the lungs.

2. But when the air escapes from the mouth of a breathing animal, it contains much moisture also. It enters comparatively dry—it comes out so moist as readily to deposit dew upon any cold surface, or to form a white mist in a wintry atmosphere. This water is given off by the lungs, along with the carbonic acid, and, like it, is derived from the food, solid or liquid, which has been introduced into the stomach. It may either be part of the water which has been swallowed as such, or the water which may be supposed to exist in the starch and sugar of the food. Or it may be water formed by the union of

the hydrogen of the other kinds of food with the oxygen inhaled by the lungs. It is probably derived in part from each of these sources, in proportions which must vary with many circumstances.

3. But the lungs actually feed the body. The air which enters contains more oxygen than when it returns again from the lungs. The oxygen which disappears equals in bulk very nearly that of the carbonic acid which is evolved. This oxygen enters the lungs, through them into the blood, and with the blood flows on and circulates through the body. It also enters partly into the composition of the tissues, so that it is a real food, and is as necessary to the construction of the human body as the other forms of food which are usually introduced into the stomach. The weight of oxygen taken up by the lungs exceeds considerably that of all the dry solid food which is introduced into the stomach of a healthy man. (See p. 387.)

4. The purposes served by the oxygen thus introduced into the system are very difficult and complicated. But an incidental circumstance, which accompanies all its operations in the system, is the evolution of heat. From the time the solid digestible food enters the blood till it escapes from the lungs, or in the other excretions, it is continually uniting with oxygen into new forms of combination, and at each change heat is produced or given off. Thus the animal heat is kept up, and thus it is, in a certain sense, correct to say that oxygen is taken in by the lungs for the purpose of giving warmth to the body— or, more poetically, that the body is a lamp fed with oil from the stomach, and with air from the lungs, which burns with a slow and invisible flame, but which ever does burn while life lasts, and maintains a gentle warmth through all its parts.

SECTION III.—THE FOOD MUST REPAIR THE DAILY WASTE OF THE MUSCULAR PARTS AND TISSUES OF THE BODY.

From every part of the growing as well as of the full-grown body, a portion is daily abstracted by natural processes, and rejected either through the lungs and skin, or in the solid and fluid excretions. This proportion is so great that in summer the body loses one-fourteenth, and in winter one-twelfth of its weight daily, when no food is taken. And if food be continuously withheld, the mean duration of human life is only fourteen days, and the weight diminishes two-fifths. But the waste or change of material proceeds more rapidly when the animal is well fed, so that the opinion now prevails among physiologists that every twenty or thirty days the greater part of the matter of the human body, when adequately fed, is constantly renewed. This waste of the tissues is more rapid in women than in children, in men than in women, and most of all in men between the ages of 30 and 40. The amount of waste is the measure of life.

The materials for this change must be supplied by the food. And the quantities required must be adapted to the nature, age, and sex of the animal.

The muscles of animals, of which lean beef and mutton are examples, are generally coloured by blood; but when washed with water for a length of time, they become quite white, and, with the exception of a little fat, are found to consist of a white fibrous substance, to which the name of *fibrin* has been given by chemists. The clot of the blood consists chiefly of the same substance; while skin, hair, horn, and the organic part of the bones, are composed of varieties of *gelatine*. This latter substance

is familiarly known in the form of *glue*, and though it differs in its sensible properties, it is remarkably similar to *fibrin* in its elementary composition, as well as to the white of the egg, (*albumen*,) to the curd of milk, (*casein*,) and to the *gluten* of flour. They all contain nitrogen, and the three latter consist of the four organic elementary bodies very nearly in the following proportions :—

Carbon, ...	55
Hydrogen, ...	7
Nitrogen, ...	16
Oxygen, with a little sulphur and phosphorus,	22
	100

Gelatine or dry glue contains about 2 per cent more nitrogen.

The quantity of one or other of these substances removed from the body in 24 hours, either in the perspiration, (p. 385,) or in the excretions, amounts to *about five ounces*, containing 350 grains of nitrogen ; and this waste *at least* must be made up by the gluten, fibrin, or other protein compounds of the food.

In the 1¾ lb. of wheaten bread, supposed in the previous section to be eaten to supply the carbon given off by the lungs, there will be contained also about 3 ounces of *gluten* —a substance nearly identical with *fibrin*, and capable of taking its place in the animal body. Let the other two ounces which are necessary to supply the daily waste of muscle, &c. be made up in beef, of which half a pound contains 2 ounces of dry fibrin, and we have—

	For respiration.	For waste of muscle, &c.
1¾ lb. of bread yielding	18 oz. starch and	3 oz. of gluten.
8 oz. of beef yielding	...	2 oz. of fibrin.
Total consumed by respiration and the ordinary waste,	18 oz. starch and	5 oz. gluten or fibrin.

If, again, the $7\frac{1}{2}$ lb. of potatoes be eaten, then in these are contained about $2\frac{1}{2}$ ounces of gluten or albumen, so that there remain $2\frac{1}{2}$ ounces to be supplied by beef, eggs, milk, or cheese.

The reader, therefore, will understand why a diet, which will keep up the human strength, is easiest compounded of a mixture of vegetable and animal food. It is not merely that such a mixture is more agreeable to the palate, or even that it is absolutely necessary—for, as already observed, the strength may be fully maintained by vegetable food alone ;—it is because, without animal food in one form or another, so large a bulk of the more common varieties of vegetable food requires to be consumed in order to supply the requisite quantity of nitrogen in the form of gluten, albumen, &c. Of ordinary wheaten bread alone, about 3 lb. daily must be eaten to supply the nitrogen,* and there would then be a considerable waste of carbon in the form of starch, by which the stomach would be overloaded, and which, not being worked up by respiration, would pass off in the excretions. The wants of the body would be equally supplied, and with more ease, by $1\frac{3}{4}$ lb. of bread, and 4 ounces of cheese.

Oatmeal, again, contains at least one-half more nitrogen than the wheaten flour of our climate (p. 313,) and hence 2 lb. of it will usually go as far in supplying this portion of the natural waste as 3 lb. of wheaten flour, and the stomach will be less oppressed. This fact throws much light on the use and value of what has been called the natural food of Scotland.

The stomach and other digestive apparatus of our domestic animals are of larger dimensions, and they are

* The dry flour being supposed to contain 15 per cent of dry gluten, (a large proportion,) on which supposition all the above calculations are made.

able, therefore, to contain with ease as much vegetable food, of almost any wholesome variety, as will supply them with the quantity of nitrogen they may require. Yet every feeder of stock knows that the addition of a small portion of oil-cake, or of bean-meal, substances rich in nitrogen, will not only fatten an animal more speedily, but will also save a large *bulk* of other kinds of food.

SECTION IV.—THE FOOD MUST SUPPLY THE SALINE AND EARTHY MATTERS CONTAINED IN AND DAILY REJECTED BY THE BODY.

The full-grown animal daily rejects a quantity of saline and earthy matter withdrawn from its wasting tissues; while the growing animal appropriates also every day an additional portion in the formation of its increasing parts. The food must yield all this, or the functions will be imperfectly performed.

1. *The flesh, the blood, and the other fluids* of the body, contain much *saline* matter of various kinds—sulphates, muriates, phosphates, and other saline compounds of potash, soda, lime, and magnesia. The dry muscle and blood of the ox leave, when burned, about 4½ per cent of saline matter or ash. The composition of this saline matter is represented in the following table of Enderlin :—

	Blood.	Flesh.
Phosphate of soda, (tribasic,)	16.77	45.10
Chloride of sodium, (common salt,)	59.34	45.94
Chloride of potassium,	6.12	
Sulphate of soda,	3.85	trace.
Phosphate of magnesia,	4.19	6.84
Oxide, with a little phosphate of iron,	8.28	
Sulphate of lime, gypsum, and loss,	1.45	
	100	97.88

All these saline substances have their special functions to perform in the animal economy, and of each of them

an undetermined quantity daily escapes from the body in the perspiration, in the urine, or in the solid excretions. This quantity, therefore, must be daily restored by the food.

2. It is interesting to remark how the mineral matter differs in kind in the different parts of the body. Thus, blood contains much soda and little potash—the former in the serum, the latter in the globules—the cartilages much soda and no potash, and the muscles much potash and little soda. So phosphate of lime is the earth of bones, and phosphate of magnesia the earth of the muscles. So also the presence of fluorine characterises the bones and teeth, and that of silica, the horny parts, hair and feathers of animals—while an abundance of iron distinguishes the blood and the hair.

The distinction now noticed between the blood and the muscle is not brought clearly out by the analysis above given of the comparative composition of the saline matter of each. It is seen more clearly in the following comparison :—

	The mineral matter or ash of ox blood contains, per cent.	of ox flesh contains, per cent.
Common salt, . .	47 to 51	—
Chloride of potassium, .	— —	10
Potash, . . .	7 - 8	36
Soda, . . .	12 - 14	—
Phosphoric acid, . .	3 - 7	35
Oxide of iron, . .	7 - 10	1

From the blood, therefore, as a common storehouse, each part obtains, by a kind of selection, the mineral matter which it specially requires.

It has not yet been accurately determined by experiment how much saline matter must necessarily be excreted every day from the body of a healthy man, or in what proportions the different inorganic substances are

present in what is excreted ; but it is satisfactorily ascertained, that without a certain *sufficient* supply of all of them, the animal will languish and decay, even though carbon and nitrogen, in the form of starch and gluten, be abundantly given to it. It is a wise and beautiful provision of nature, therefore, that plants are so organised as to refuse to grow in a soil from which they cannot readily obtain an adequate supply of soluble inorganic food,—since that saline matter, which ministers first to their own wants, is afterwards surrendered by them to the animals they are destined to feed.

Thus, the dead earth and the living animal are but parts of the same system,—links in the same endless chain of natural existences. The plant is the connecting bond by which they are tied together on the one hand,—the decaying animal matter, which returns to the soil, connects them on the other.

3. *The bones of the animal* are supplied with their mineral matter from the same original source,—the vegetable food on which they live. The dried bones of the cow contain 55 per cent of phosphate of lime with a little phosphate of magnesia, those of the sheep 70, of the horse 67, of the calf 54, and of the pig 52 lb. of these phosphates in every hundred of dry bone. All this must come from the vegetable food. Of this bone-earth, also, a portion—varying in quantity with the health, the food, and the age of the animal—is every day rejected. The food, therefore, must contain a daily supply, or that which passes off will be taken from the substance of the living bones, and the animal will become feeble.

The importance of this bone-earth will be more apparent, if we consider,—*First*, that in animals the bones form not only a very important, but a very large part of their bodies. The body of a full-grown man contains

9 to 12 lb. of clean dry bone, yielding from 6 to 8 lb. of bone-earth. In the horse and sheep the fresh moist bone has been estimated at one-eighth of the live, or in the sheep to one-fifth of the dead weight, and to one-third of the weight of the flesh. *Second*, that in a growing sheep the increase of bone-earth amounts to about 3 per cent of the whole increase in the live weight. And —*Third*, that every hundred pounds of live weight indicates 5 or 6 of phosphate of lime.

It is kindly provided by nature, therefore, that a certain proportion of this ingredient of bones is always associated with the gluten of plants in its various forms,— with the fibrin of animal muscle and with the curd of milk. Hence man, from his mixed food, and animals, from the vegetables on which they live, are enabled, along with the nitrogen they require, to extract also a sufficiency of bone-earth to maintain their bodies in a healthy condition.

SECTION V.—THE FOOD MUST SUPPLY THE WASTE OR INCREASE OF FAT IN ANIMALS.

Every one knows that in some animals there is much more fat than in others, but in all a certain portion exists, more or less intermingled with the muscular and other parts of the body.* This fat is subject to waste, as the muscles are, and therefore must be restored by the food. All the vegetable substances usually cultivated on our farms contain, as we have seen, (p. 338,) a notable quantity of fatty matter, which seems to be intended by

* At Port Philip, in the boiling-houses, a Merino sheep of 55 lb. gives 20 lb. of tallow, and of all weight above 55 lb. four-fifths are tallow.

nature to replace that which disappears naturally from the body.

A full-grown animal, in which the fat may be regarded as in a stationary condition, requires no more fat in its food than is necessary to restore the natural loss. In such an animal the quantity of fatty matter found in the excretions is sensibly equal to that which is contained in the food.

But to a growing animal, and especially to one which is *fattening*, the supply of fatty matter in the food must be greater than to one in which no increase of fat takes place. It is indeed held, that, in the absence of oil in the food, an animal may convert a portion of the starch of its food into fat,—may become fat while living upon vegetable food in which no large proportion of fatty matter is known to exist. And it can hardly be doubted, I think, that the organs of the living animal are endowed with this power of forming in a case of emergency—that is, when it does not exist ready formed in the food—as much fatty matter as is necessary to oil the machinery, so to speak, of its body. But the natural source of the fat is the oil contained in the food it eats, and an animal, *if inclined to fatten at all*, will always do so most readily when it lives upon food in which oil or fat abounds.

It does not however follow, because fat abounds in the food, that the animal should become fatter,—since if starch be deficient in the food, the fat, containing no nitrogen, may be decomposed and worked up for what may be called the purposes of respiration. This working up of the fat, already existing in the body, is one cause of the rapid emaciation and falling away of fat animals when the usual supply of food is lessened, or for a time altogether withheld. The fat is indeed considered by some as nothing more than a store laid up by nature

in a time of plenty to meet the wants of respiration when a season of scarcity arrives,—that a fat animal is like a steam-frigate heavily laden with fuel, which it burns away during its voyage for the purpose of keeping up the steam.

It is by reference to this supposed purpose of the fat of the body, and to the possibility of using it up for the purposes of respiration, that the benefits of repose, of shelter, of moderate warmth, of the absence of light, and even of a state of torpor, in conducing to the more speedy fattening of cattle and sheep, are explained. Exercise causes more frequent respirations, and hence a greater waste of that part of the food which should be laid on in the form of fat. Cold also has the same effect, since more heat must be produced in the interior of the animal—in other words, more frequent respiration must take place, in order to make up for the greater loss of heat by exposure to the external air.

Thus, as was stated at the commencement of the present chapter, a study of the nature and functions of the food of animals throws additional light upon the nature also and final uses of the food of plants. It even teaches us what to look for in the soil—what a fertile soil *must* contain that it may grow nourishing food — what we must add to the soil when chemical analysis fails to detect its actual presence, or when the food it produces is unable to supply all that the animal requires.

SECTION VI.—SPECIAL WASTE IN THE PERSPIRATION OF ANIMALS, AND IMPORTANCE OF THIS FUNCTION.

Animals perspire that they may live, and this function is as necessary to a healthy life as either breathing or digestion. The skin, like the lungs, gives off carbonic acid

and absorbs oxygen. But it differs from the lungs in giving off a much larger bulk of the former gas than it absorbs of the latter. The quantity of carbonic acid which escapes varies with circumstances. It is sometimes equal to a thirtieth, and sometimes amounts only to a ninetieth part of that which is thrown off from the lungs. But exercise and hard labour increase the evolution of carbon from the skin, as it does from the lungs. In motion, the human body gives off nearly three times as much as when it is at rest; while from a horse, when put to the trot, the carbonic acid of the skin augments as much as an hundred and seventy times. (GERLACH.)

Water is also given off from the skin as from the lungs, and every one knows that fat exudes from its pores and lubricates the surface of the body. The salt taste of the perspiration is an equally familiar proof that a portion, at least, of the saline matter derived from the waste and change of materials in the body escapes through this channel.

Nitrogen also escapes from the skin. The quantity of nitrogen in the food is a third or a fourth greater than that contained in the solid and liquid excretions.—(BARRAL.) This third or fourth, therefore, is supposed to be given off by the organs of perspiration, the lungs and the skin. A cow or a horse is reckoned to exhale by the skin and lungs about 400 grains of nitrogen daily; a man, perhaps, 100; and a sheep or pig 80 grains. (BOUSSINGAULT.)

The functions of the skin, therefore, are very important; and thus, in the practical feeding of animals, a healthy and clean condition of the skin must contribute not only to healthy growth, but to a profitable employ-

ment of vegetable produce in rearing, maintaining, and fattening them.*

SECTION VII.—FORMS IN WHICH THE SOLID MATTERS OF THE TISSUES ESCAPE IN THE URINE.

The lungs throw off, in the form of gas or vapour, a large proportion of the matters which, after being taken into the stomach, have already served their purpose in the body. The kidneys remove the greater part of that which is derived from the destruction of the tissues. The solid excretions in man amount only to a fourteenth or an eighteenth of the whole food consumed.

In a state of health, the saline substances of the food escape for the most part in the urine. The mineral matter contained in that part of the solid excretions which has undergone digestion, consists chiefly of earthy salts and of iron.

In man, and in our domestic animals, the nitrogen of the food and tissues is also separated from the blood by the kidneys, and is found in the urine. It is chiefly in the form of a substance to which the name of urea is given. In birds, serpents, and insects, it is separated in the form of uric acid. The urine voided by a healthy man in 24 hours, averages about 40 ounces, and contains about 150 grains of solid matter which has served its purpose in the system. Of this solid matter, about 270 grains consist of urea, 8 of uric acid, and 170 of mineral or saline matter. The urine of the horse is richer in urea

* Six pigs were put up together for seven weeks. Three were curry-combed and cared for—the other three left to themselves; the former three consumed 5 bushels of pease less, and had gained 2 stones 4 pounds more, than the uncurried three. The skins of pigs fed in the forest, in the season of the acorns, are white and shining.

than that of the cow, and that of the cow than the urine of man. It is this urea which, during the fermentation or ripening of urine, becomes changed into ammonia.

The urea and uric acid discharged daily in the urine of a healthy man, contains about half an ounce of nitrogen —to furnish which requires 3 ounces of dry gluten, albumen, or flesh. If so large a proportion of that which is most valuable in food, and which has been derived from the decay of the tissues of the body, is contained in the urine, it ought to be an important object to the farmer to contrive some method of returning it without loss to the soil, that it may aid again in raising new vegetables as food for other animals.

SECTION VIII. — GENERAL BALANCE OF FOOD AND EXCRETIONS IN MAN.

The general balance of the food taken into the human body, and of the excretions of various kinds, has been thus represented by M. Barral:—

Every 100 *parts taken in, consist of—*

Food, solid and liquid, containing in all 75 per cent of water,	74.4
Oxygen taken in by the lungs, ...	25.6
	100

And are given off as—

Water perspired by the lungs and skin, ...	34.8
Carbonic acid, do. do., ...	30.2
Evacuations, solid and liquid, ...	34.5
Other losses, ...	0.5
	100

In general, the substances perspired are to the evacuations as 2 to 1.

Of course, in an estimate of this kind, it is impossible accurately to put down the several quantities given off in the form of hair, nails, surface skin—both of the outer and

inner parts of the body—&c., &c., all of which are constantly shed or cut, and as constantly renewed. It is useful, however, in showing generally the relation which the oxygen inspired bears to the other food which the stomach receives, and the proportion of the work of excretion performed respectively by the perspiring organs, and by the organs of evacuation.

SECTION IX.—KIND OF FOOD REQUIRED BY ANIMALS AS INDICATED BY THE COMPOSITION OF THE BLOOD.

A knowledge of the kind of food required by animals may be gathered, as we have seen, from the composition of the several parts of the animal body, and a study of the functions they perform. The muscles must be sustained; therefore gluten, albumen, &c.—often popularly called muscular matter—must be eaten. The fat of the body must be renewed, and hence fat should be present in the food. And as much carbon escapes from the lungs and skin, it seems natural, if not absolutely necessary, that starch or sugar should be introduced into the stomach with the view of supplying it. The mineral matter of the flesh, blood, and bones, must in like manner be provided.

The study of the excretions indicates, besides, the quantity of food of each kind which ought to be consumed. The quantity of carbon evolved in the form of carbonic acid, of nitrogen in the forms of urea and uric acid, and of saline matters in the urine and solid excretions of a healthy man, afford a means of approximating very nearly to the quantity of each which a sufficient food ought to contain; but the excretions do not alone tell us in what forms the carbon, nitrogen, and saline matters are best suited to the wants of the animal.

An examination of the blood gives us this latter information very clearly. The blood consists essentially, besides the water, of albumen, sugar, fat, and saline matter. The main purpose or object of the process of digestion is to form blood; for out of the blood are drawn the materials necessary to the wants of the bones, and of the various tissues and fluids of the body. Those forms of vegetable or animal matter, therefore, must be best adapted for food, which most resemble the ingredients of the blood which is to be produced from them. These will give the digestive organs least trouble, or will be most easily digested. Thus we arrive again at the conclusion that a healthy, nourishing, and easily digestible food ought to contain gluten or albumen, sugar or starch —which, in the stomach, readily changes into sugar—fat either of animal or vegetable origin, and saline or mineral matters of various kinds. Of course, if the stomach of the animal be in an unhealthy condition, the quality of the food may require to be adapted to its unnatural condition; but this does not affect our general conclusion.

SECTION X.—IMPORTANCE OF A MIXED FOOD.

All these different modes of examining the question, therefore, indicate not only the advantage but the necessity of a mixed food to the healthy sustenance of the animal body. Hence the value of any vegetable production, considered as the *sole* food of an animal, cannot be accurately determined by the amount it may contain of any *one* of those substances, *all* of which together are necessary to build up the growing body of the young animal, and to repair the natural waste of such as have attained to their fullest size.

Hence the failure of the attempts that have been made

to support the lives of animals by feeding them upon pure starch or sugar alone. These substances would supply the carbon perspired by the lungs and the skin; but all the natural waste of nitrogen, of saline matter, of earthy phosphates, and probably also of fat, must have been withdrawn from the existing solids and fluids of their living bodies. The animals, in consequence, pined away, became meagre, and sooner or later died.

So some have expressed surprise that animals have refused to thrive—have ultimately died, when fed upon animal jelly or gelatine alone, nourishing though that substance *as part of the food* undoubtedly is. When given in sufficient quantity, gelatine might indeed supply carbon enough for respiration, with a great waste of nitrogen, but it is deficient in the saline ingredients which a naturally nourishing food contains.

Even on the natural mixture of starch and gluten which exists in fine wheaten bread, dogs have been unable to live beyond 50 days, though others fed on household bread, containing a portion of the bran—in which earthy matter more largely resides—continued to thrive long after. It is immaterial whether the general quantity of the *whole* food be reduced too low, or whether *one* of its necessary ingredients only be too much diminished or entirely withdrawn. In either case the effect will be the same—the animal will become weak, will dwindle away, and will sooner or later die.

The skill of the feeder may often be applied with important economical effects to the proper selection and mixture of the food he gives his animals generally, and at various stages of their growth.

It has been found by experiment, for example, that food which, when given alone, does not fatten, acquires that property in a high degree when mixed with some

fatty substance, and that those which are the richest in the muscle-forming ingredients produce a comparatively small effect unless they contain also, or are mixed with, a considerable proportion of fatty matter. Hence the reason why a stone of linseed has been found by some to go as far as two stones of linseed cake, and why the Rutlandshire farmers find a sprinkling of linseed oil upon the hay to be a cheap, wholesome, and fattening addition to the food of their cattle and horses.

A Merino sheep of 55 lb. contains about 20 lb. of fat, but four-fifths of any subsequent addition consists of tallow, (p. 382 note ;) hence we may infer that oily food should be profitable in fattening sheep. To pigs the same remark applies ; and, in practice, fat of any kind, animal or vegetable, is found to be a profitable addition to the food of these animals when they are to be fattened off.

CHAPTER XXV.

Feeding of animals continued.—Kind and quantity of food necessary to maintain a healthy man.—Prison dietaries.—Food required by other animals.—Practical value of the constituents of milk in feeding the growing calf.—Effect of long-continued dairy husbandry upon the quality and produce of the soil.—On the growing of wool, and its effect upon the soil.—Of the practical and theoretical values of different kinds of food.—Relative proportions of food for man yielded by the same herbage in the forms of beef and milk.—Influence of circumstances in modifying the practical values of animal and vegetable food.—Concluding observations.

PRACTICAL experience sustains and confirms all the theoretical views, and the deductions, chemical and physiological, which have been advanced in the preceding chapter. To a few of these practical confirmations I shall briefly advert.

SECTION I.—KIND AND QUANTITY OF FOOD NECESSARY TO MAINTAIN A HEALTHY MAN.—PRISON DIETARIES. —FOOD REQUIRED BY SHEEP AND CATTLE.

The dietaries of prisons, and their effects on the bodily health and weight of the prisoners, afford one of the simplest methods of testing the influence of kind and quantity upon the nourishing power of food. In such establishments—though open to the objection that the prisoners are in a state of unusual restraint—experiments can be performed so much more accurately, and

on so much larger a scale than elsewhere, as to make them worthy of a very considerable amount of confidence.

An inquiry lately made into the comparative health and food of the inmates of the Scotch prisons, has afforded very interesting materials for proving the necessity of a mixed food, and of a certain minimum proportion of that kind of food which is supposed especially to sustain the muscular and other tissues.

In the course of the preceding chapter we have stated :

1° That a healthy man in ordinary circumstances voids daily about half an ounce of nitrogen in his urine alone, (p. 387.) To supply this he would require to consume three ounces of dry gluten, albumen, or flesh.

2°. That altogether he gives off from the lungs, skin, and kidneys, about 350 grains, or five-sevenths of an ounce, to supply which he must consume about five ounces of the same materials, (p. 377.)

But in a state of temporary confinement, when not subjected to hard labour, this quantity may be safely diminished. Yet even here there is a limit below which it is unsafe to go. In the Scotch prisons the weight of food given to prisoners confined for not more than two months, and not subjected to hard labour, is uniformly about 17 ounces, and the proportion of gluten or nitrogenous food contained in this is about four ounces. Where this proportion is maintained, the average general health and weight of the prisoners improves during their confinement. Where the contrary is the case, the weight diminishes, and the health declines. This is shown in the following tabular view of the kinds and weight of food given in five of the Scotch prisons, and its effects upon the weight of the prisoners :—

Jail.	Food given.			Per-centage of prisoners who lost weight.
	Nitrogenous.	Carbonaceous.	Total.	
Edinburgh,	4 oz.	13 oz.	17 oz	18 lost 1½ lb. each
Glasgow,	4.06	12.58	16.84	32.66 4 ,,
Aberdeen,	3.98	13.03	17	32 4.2 ,,
Stirling	4.27	13.4	17.67	
Dundee,	2.75	14	16.75	50 4.35 ,,

This table shows that, with the Edinburgh dietary and management, 72 per cent of the prisoners either maintained or increased their weight, while only 18 per cent diminished in weight, and that only to the small extent of 1½ lb. each. In Glasgow the result was less favourable, though even there, out of nearly 500 prisoners, only one-third diminished in weight. The same was the case at Aberdeen and Stirling; so that in these three places the diet may be regarded as, on the whole, sufficient. But in Dundee, one-half of the prisoners (50 per cent) lost weight during their short confinement; and the cause is obvious, in the diminished proportion of muscle-forming food, which in this case was reduced to 2¾, in place of 4 ounces.

And it is an interesting fact, as marking the close connection between science and practice, that this deterioration in the quality of the diet was caused by the *substitution of molasses for the milk*, which had been previously distributed to the prisoners along with their porridge of oatmeal. Milk is rich in nitrogenous food, while molasses contains none; and the substitution was immediately followed by a perceptible falling off in the health and weight of the prisoners. So general are the evils which may arise from ignorance or disregard of scientific principles in a single director or directing body.

The apparently trivial substitution of molasses for milk brought weakness and want of health on the inmates of an entire prison.

In the feeding of other animals, similar results follow from similar inattention to the requirements of animal nature. Of dry hay it has been found, in practice, that cattle and sheep require for their daily food—

An ox at rest,	2	per cent of his live weight.	
... at work,	2½	...	...
... fatting,	5	...	at first.
... half fat,	4½	...	...
... when fat,	4	...	...
Milch cow,	3	...	...
Sheep, full grown,	3½	...	...

In the case of the ox the daily waste or loss of muscle and tissue requires that he should consume 20 to 24 ounces of gluten or albumen, which, as may be calculated from the table given in a subsequent section, (p. 401,) will be supplied by any of the following weights of vegetable food:—

Meadow hay, . . .	20 lb.	Turnips, ...	120 lb.
Clover hay, ...	16 „	Cabbage, ...	70 „
Oat straw, ...	110 „	Wheat or other white grain,	11 „
Pea straw, ...	12 „	Beans or pease, ...	6 „
Potatoes, ...	60 „	Oil-cake, ...	4 „
Carrots, ...	70 „		

Or instead of any one of these, a mixture of several may be given, with the best results. But if the due proportion of nitrogenous food be not given, the ox will lose his muscular strength, and will generally fail. So with growing and fatting stock of every kind, the proportion of each of the kinds of food required by the animal must in practice be adjusted to the purpose for which it is fed, as theory indicates, or actual money loss will ensue to the feeder.

SECTION II.—PRACTICAL VALUE OF SALINE AND OTHER INGREDIENTS OF MILK IN FEEDING THE GROWING CALF.

In the course of the preceding section I have incidentally remarked, that the substitution of molasses for milk lowered the proportion of nitrogenous food in the Dundee prison diet, and rendered it insufficient for the healthy maintenance of the prisoners. The reason of this appears in the composition of milk, already given in a previous chapter. The consideration of milk as a natural food supplies us with another beautiful practical illustration of our theoretical principles, to which I shall briefly advert; and I do so, not merely because of the light it throws upon the supply of nitrogen which a milk diet is fitted to yield, but because it so clearly illustrates another of the positions laid down in the preceding chapter, that the food must supply, in kind and quantity, all the saline and earthy substances contained in the body.

Milk is a true food. It contains sugar, casein, saline matter, and fat—a portion of each of those classes of substances on which the herbivorous races live in the most healthy manner. But the provision is very beautiful by which the young animal—the muscle and bones of which are rapidly growing—is supplied, not only with a larger proportion of nitrogenous food, but also of bone-earth, than would be necessary to maintain the healthy condition of a full-grown animal of equal size. The milk of the mother is the natural food from which its supplies are drawn. The sugar of the milk supplies the comparatively small quantity of carbon necessary for the respiration of the young animal. As it gets older, the calf or young lamb crops green food for itself to supply an additional portion. The curd of the milk (*casein*) yields the

materials of the growing muscles and of the organic part of the bones; while along with the curd, and dissolved in the liquid milk, is the phosphate of lime, of which the earthy part of the bones is to be built up. A glance at the composition of milk will show us how copious the supply of all these substances is,—how beautifully the composition of the mother's milk is adapted to the wants of her infant offspring. Cow's milk consists in 1000 parts by weight of about—

Butter,	27
Cheesy matter, (casein,)	45
Milk-sugar,	36
Chloride of potassium, and a little common salt,	1¼
Phosphates, chiefly of *lime*,	2¼
Other saline substances,	6
Water,	882½
	1000

The quality of the milk, and consequently the proportions of the several constituents above mentioned, vary, as I have explained in a preceding chapter, with the breed of the cow—with the food on which it is supported—with the time that has elapsed since the period of calving—with its age, its state of health, and with the warmth of the weather;* but in all cases this fluid contains the same substances, though in different quantities and proportions.

Milk of the quality above analysed contains, in every 10 gallons, 4½ lb. of casein, equal to the formation of 18 lb. of ordinary muscle,—and 3½ ounces of phosphate of lime, (bone-earth,) equal to the production of 7 ounces of dry bone. But from the casein have to be formed the skin, the hair, the horn, the hoof, &c., as well as the muscle; and in all these is contained also a minute quantity of the bone-earth. A portion of all the ingredients

* In warm weather the milk contains more butter, in cold weather more cheese and sugar.

of the milk likewise passes off in the ordinary excretions, and yet every one knows how rapidly young animals thrive, when allowed to consume the whole of the milk which nature has provided as their most suitable nourishment.

SECTION III.—EFFECT OF LONG-CONTINUED DAIRY HUSBANDRY UPON THE QUALITY AND PRODUCE OF THE SOIL.

And whence does the mother derive all this gluten and bone-earth, by which she can not only repair the natural waste of her own full-grown body, but from which she can spare enough also to yield so large a supply of nourishing milk?

She must extract them from the vegetables on which she lives, and these again from the soil.

The quantity of solid matter thus yielded by the cow in her milk is really very large, if we look at the produce of an entire year. If the average yield of milk be 3000 quarts, or 750 gallons, in a year, (every 10 gallons of which contain bone-earth enough to form about 7 ounces of dry bone,) then by the milking of the cow alone we draw from her the earthy ingredients of 33 lb. of *dry* bone in a year. These are equal to 40 lb. of common bone-dust, or $3\frac{1}{3}$ lb. in a month. And these she draws necessarily from the soil.

If this milk be consumed on the spot, then all returns again to the soil on the annual manuring of the land. Let it be carried for sale to a distance, or let it be converted into cheese and butter, and in this form exported —there will then be yearly drawn from the land from this cause alone a quantity of the materials of bones which can only be restored by the addition of 40 lb. of

bone-dust to the land. If to this loss from the milk we add only 10 lb. for the bone carried off by the yearly calf,* the land will lose by the practice of dairy husbandry as much bone-earth as is contained in 50 lb. of bone-dust — or in 45 years every imperial acre of land will lose what is equivalent to a ton of bones.

After the lapse of centuries, therefore, we can easily understand how old pasture lands, in cheese and dairy countries, should become poor in the materials of bones —and how in such districts, as is now found to be the case in Cheshire, the application of bone-dust should entirely alter the character of the grasses, and renovate the old pastures.

SECTION IV.—OF THE GROWING OF WOOL, AND ITS EFFECT UPON THE SOIL.

The rearing of wool affords another beautiful practical illustration, both of the kind of food which animals require for particular purposes, and of the effect which a peculiar husbandry must slowly produce upon the soil.

Wool and hair are distinguished from the fleshy parts of the animal by the large proportion of sulphur they contain. Perfectly clean and dry wool contains about 5 per cent of sulphur—or every 100 lb. contain 5 lb.

The quantity as well as the quality of the wool yielded by a single sheep varies much with the breed, the climate,

* It has been estimated that the proportion of bone in the—

Horse, ...	= $\frac{1}{8}$ of the live weight.
Sheep, *old*, (Merino,) .	= $\frac{1}{8}$ of *live*, $\frac{1}{5}$ of *dead* do.
	= $\frac{1}{3}$ nearly of *flesh and fat*.
Pig, unfatted, . . .	= $\frac{1}{6}$ of *live*, $\frac{1}{5}$ of *dead* do.

And *generally*, that 100 live weight indicate 2 to 3 of phosphoric acid; but these proportions are, no doubt, subject to great variation.

the constitution, the food, and consequently with the soil on which the food is grown. The Hereford sheep, which are kept lean, and give the finest wool, yield only $1\frac{1}{2}$ lb.; but a Merino often gives a fleece weighing 10 or 11 lb., and sometimes as much as 12 lb.

The number of sheep in Great Britain and Ireland amounts to 30 millions, and their yield of wool to 111 millions of pounds, or about 4 lb. to the fleece. This quantity of wool contains 5 millions of pounds of sulphur, which is of course all extracted from the soil.

If we suppose this sulphur to exist in, and to be exracted from, the soil in the form of gypsum, then the plants which the sheep live upon must *take out* from the soil, to produce the wool alone, 30 millions of pounds, or 13,000 tons of gypsum.

Now, though the proportion of this gypsum lost by any one sheep-farm in a year is comparatively small, yet it is reasonable to believe that, by the long growth of wool on hilly land, to which nothing is ever added, either by art or from natural sources, those grasses must gradually cease to grow in which sulphur most largely abounds, and which favour, therefore, the growth of wool. In other words, the produce of wool is likely to diminish, by lapse of time, where it has for centuries been yearly carried off the land; and, again, this produce is likely to be increased in amount when such land is dressed with gypsum, or with other manure in which sulphur naturally exists. Of course, this general conclusion will not apply to localities which derive from springs or other natural sources a supply of sulphur equal to that which is yearly removed.

SECTION V.—OF THE PRACTICAL AND THEORETICAL VALUES OF DIFFERENT KINDS OF FOOD.

From what has been stated in the preceding sections, it appears, as the result both of theory and of practice, that different kinds of food are not equally nourishing. This fact is of great importance, not only in the preparation of human food, but also in the rearing and fattening of stock. It has, therefore, been made the subject of *experiment* by many practical agriculturists, with the following general results:

1. If common hay be taken as the standard of comparison, then, to yield the same amount of nourishment as 10 lb. of hay, experiments on feeding made by different persons, and in different countries, say that a weight of the other kinds of food must be given, which is represented by the number opposite to each in the following table:—

Hay, . .	10	Carrots, (white,)	45
Clover hay, .	8 to 10	Mangold-wurtzel,	35
Green clover,	45 „ 50	Turnips, .	50
Wheat straw,	40 „ 50	Cabbage, .	20 to 30
Barley straw,	20 „ 40	Pease and beans,	3 „ 5
Oat straw, .	20 „ 40	Wheat, . .	5 „ 6
Pea straw, .	10 „ 15	Barley, . .	5 „ 6
Potatoes, .	20	Oats, . .	4 „ 7
Old potatoes, .	40?	Indian corn, .	5
Carrots, (red,)	25 „ 30	Oil-cake, .	2 „ 4

It is found in practice, as the above table shows, that twenty stones of potatoes, or three of oil-cake, will nourish an animal as much as ten stones of hay will, and five stones of oats as much as either. Something, however, will depend upon the quality of the sample of each kind of food used—which we know varies very much, and with numerous circumstances; and something also upon the age and constitution of the animal, and upon

the way and form in which the food is administered. The skilful rearer, feeder, and fattener of stock knows also the value of a change of food, or of a mixture of the different kinds of vegetable food he may have at his command—a subject we have considered in a previous section.

2. The generally nutritive value of different kinds of food has also been represented *theoretically*, by supposing it to be very nearly in proportion to the quantity of nitrogen, or of gluten, which vegetables contain. Though this cannot be considered as a correct principle, yet, as the ordinary kinds of food on which stock is fed contain in general an ample supply of carbon for respiration, with a comparatively small proportion of nitrogen, these theoretical determinations are by no means without their value, and they approach, in many cases, very closely to the practical values above given, as deduced from actual trial. Thus, assuming that 10 lb. of hay yield a certain amount of nourishment, then of the other vegetable substances it will be necessary, according to theory, to give the following quantities, in order to produce the same general effect in feeding:—

Hay,	10	Carrots, (red,)	35
Clover hay,	8	Cabbage,	30 to 40
Vetch hay,*	4	Pease and beans,	2 to 3
Wheat straw,	52	Wheat,	5
Barley straw,	52	Barley,	6
Oat straw,	55	Oats,	5
Pea straw,	6	Rye,	5
Potatoes,	28	Indian corn,	6
Old potatoes,	40	Bran,	5
Turnips,	60	Oil-cake,	2
Mangold-wurtzel,	50		

If the feeder be careful to supply his stock with a mixture or occasional change of food—and especially, where necessary, with a proper proportion of fatty matter

* Both cut in flower.

— he may very safely regulate, by the numbers in the above tables, the quantity of any one which he ought to substitute for a given weight of any of the others—since the theoretical and practical results do not in general very greatly differ.

3. As has been already stated, however, it is not strictly correct that this or that kind of vegetable is more fitted to sustain animal life, simply because of the larger proportion of nitrogen or gluten it contains ; but it is wisely provided that, along with this nitrogen, all plants contain a certain proportion of starch or sugar, and of saline and earthy matter—all of which, as we have seen, are required in a mixture which will most easily sustain an animal in a healthy condition ; so that the proportion of nitrogen in a substance may be considered as a rough *practical* index of the proportion of the more important saline and earthy ingredients also.

4. It is very doubtful, however, how far this proportion of nitrogen can be regarded as any index of the *fattening* property of vegetable substances. If the fat in the body be produced from the oil in the food, it is certain that the proportion of this oil in vegetable substances is by no means regulated by that of the gluten or other analogous substances containing nitrogen. The stock farmer who wishes to lay on fat only upon his animals, must therefore be regulated by another principle. He must select those kinds of food, such as linseed and oil-cake, in which fatty matters appear to abound, or mix, as I have already said, (p. 390,) a due proportion of fat or oil with the other kinds of food he employs.

But large quantities of fat accumulate in the bodies of most animals, only when they are in an unnatural, and, perhaps in some measure, an unhealthy condition. In a state of nature there are comparatively few animals upon

which large accumulations of fat take place. A certain portion, as we have seen, is necessary to the healthy animal; but it is an interesting fact, that as much as is necessary to supply this is present in most kinds of vegetable food. In wheaten flour it is associated with the gluten, and may be extracted from it after the starch of the flour has been separated from the gluten by washing with water, as already described (pp. 43 and 48.) In so far, therefore, as this comparatively small necessary quantity of fatty matter is concerned, the proportion of nitrogen may also be taken without the risk of any serious error, as a practical indication of the ability of the food to supply the natural waste of fat in an animal which is either growing in general size only, or is only to be maintained in its existing condition.

While, therefore, it appears from the study of the principles upon which the feeding of animals depends, that a mixture of various principles is necessary in a nutritive food, it is interesting to find that all the kinds of vegetable food which are raised, either by art or natural growth, are in reality such mixtures of these several substances — more or less adapted to fulfil all the conditions required from a nutritious diet, according to the state of health and growth in which the animal to be fed may happen to be.

An important practical lesson on this subject, therefore, is taught us by the study of the wise provisions of nature. Not only does the milk of the mother contain all the elements of a nutritive food mixed up together — as the egg does also for the unhatched bird — but in rich natural pastures the same mixture uniformly occurs. Hence, in cropping the mixed herbage, the animal introduces into its stomach portions of various plants—some abounding more in starch or sugar, some more in gluten

or albumen—some more in fatty matter—while some are naturally richer in saline, others in earthy constituents; and out of these varied materials the digestive organs select a due proportion of each and reject the rest. Wherever a pasture becomes usurped by one or two grasses—either animals cease to thrive upon it, or they must crop a much larger quantity of food to supply from this one grass the natural waste of *all* the parts of their bodies.

It may indeed be assumed as almost a general principle, that whenever animals are fed on one kind of vegetable only, there is a waste of one or other of the necessary elements of animal food, and that the great lesson on this subject taught us by nature is, that by a *judicious admixture, not only is food economised, but the labour imposed upon the digestive organs is also materially diminished.*

SECTION VI.—RELATIVE PROPORTIONS OF FOOD FOR MAN YIELDED BY THE SAME HERBAGE IN THE FORMS OF BEEF AND MILK.

A curious economical question, in connection with the value of vegetable produce in feeding cattle, presents itself to us when we come to compare the proportions of human food which may be obtained from the same weight of herbage when cattle are fed with it for different immediate purposes.

A ton of hay may be given to a bullock to be converted into beef. Another ton of the same hay may be given to a cow to be converted into milk. Would the beef or the milk produced contain the larger supply of food for man? We have rather imperfect data to rely upon in answering this question, but they lead us to very interesting results.

1. According to Sir John Sinclair, the same herbage which will add 112 lb. to the weight of an ox, will enable a cow to yield 450 wine gallons, or 3600 lb. of milk. This milk will contain 160 lb. of dry curd, 160 lb. of butter, 180 lb. of sugar, and 18 lb. of saline matter, while the 112 lb. of beef will not contain more than 25 lb. or 30 lb. of dry muscle, fat, and saline matter together; that is to say, the same weight of herbage which will produce less than 30 lb. of dry human food in the form of beef, will yield 500 lb. in the form of milk.

2. But this statement of Sir John Sinclair's is, I fear, not to be relied upon. We have another, however, something different, from Riedesel, a Continental authority. He says that the same quantity of hay will produce either 100 lb. of beef, or 100 imperial gallons (1000 lb.) of milk. This quantity of milk contains only 150 lb. of dry food, but it is still five times as much as it contained in the beef.

This statement of Riedesel is also to be received with hesitation; but the subject is interesting and important, as well as curious, and is deserving of further investigation. Should the population of the country ever become so dense as to render a rigorous economy of food a national question, butcher-meat—if the above data deserve any reliance—will be banished from our tables, and a milk diet will be the daily sustenance of almost all classes of society.

SECTION VII.—INFLUENCE OF CIRCUMSTANCES IN MODIFYING THE PRACTICAL VALUES OF ANIMAL AND VEGETABLE FOOD.

The indications of theory, and the results of general practice, in regard to the nutritive power of different

vegetable substances, are modified by many circumstances which ought to be borne in mind. Whether fed for work, or for the production of flesh or milk, the effect of the food given to animals will depend partly on the kind, breed, and constitution of the animal itself—on the general treatment to which it is subjected, and the place in which it is kept—on its size and state of health—and on the form in which the food itself is given.

1. *The breed or constitution*, every feeder knows, has a great influence on the apparent value of food. Some breeds, like the improved short-horn, have a natural tendency to fatten, which makes them increase in weight more rapidly than other breeds, when fed upon the same food. And even in the same breed, the rapidity with which one animal lays on flesh will sometimes make it two or three times more profitable to the farmer than others which are fed along with it.

2. *Warmth and shelter* cause the same amount of food to go farther, as do also gentle treatment and the absence of glaring light. Sheep have produced double the weight of mutton from the same weight of vegetable food, when fed under shelter, and kept undisturbed and in the dark. It is probably from this beneficial influence of warmth that, in the North American States, a difference of 25 per cent is observed in favour of the spring and summer over the winter feeding of pigs upon similar food.

3. *The form in which the food is given* is of no less importance. Grass newly cut goes farther than after it is made into hay; and the opinion is now becoming very generally prevalent, that steamed, boiled, or otherwise prepared food, is more wholesome for cattle, and more economical to the feeder, than the same food given in a dry state.

In the case of horses, the difference between the practice of giving all the food dry and uncut, and that of giving all the hay cut with the oats and beans crushed, and an evening meal of steamed food, is such as to affect a saving of nearly one-third. Thus, the same waggon horses which consumed 3½ bushels of oats per week, and 14 stones of hay, when given uncut, uncrushed, and uncooked, were kept in good condition by 2½ bushels of oats, 8 stones of hay, and 7 lb. of linseed when the grain was crushed, the hay cut into half-inch chaff, and the linseed with a little bean-meal and cut hay made into a steamed feed for the evening.*

4. *The malting and sprouting of barley* is by many practical men considered to increase its nutritive qualities. It is certain that, when mixed with boiled potatoes to the extent of 3 or 4 per cent, and kept warm for a few hours, bruised malt produces a prepared food which is much relished by milch cows, and is profitable to the dairyman. There is reason to believe that similar mixtures with other kinds of food would produce similar beneficial effects.

Mr Hudson, of Castle Acre, feeds his farm-horses on 12 lb. of *sprouted* barley a-day, besides their fodder ; and this, on his light land, keeps them in good condition. It is prepared by steeping the barley for 24 hours, and then putting it into a heap and turning it over for 5 days.†

5. *The souring of food* of all kinds has, by almost universal consent, been found to make it more profitable in the feeding and fattening of pigs. It makes them fatten faster, and gives a firmer and whiter flesh.

* The dry feeding being—hay 12 lb., with oats and beans 14 lb.; the steamed feed—hay 3 lb., beans 3 lb., linseed 1 lb."—*Caird's English Agriculture*, p. 346.

† *Ibid.* p. 168.

Many other circumstances also modify the real practical value of food, and cause it to produce results different from those indicated by its chemical composition. But to those, want of space does not permit me here to advert.

SECTION VIII.—CONCLUDING REMARKS.

In the little work now brought to a close, I have presented the reader with a brief, but I hope plain, and familiar sketch of the various topics connected with Practical Agriculture, on which the sciences of Chemistry, Geology, and Chemical Physiology, are fitted to throw the greatest light.

We have studied the general characters of the organic and inorganic elements of which the parts of plants are made up, and the several compounds of these elements which are of the greatest importance in the vegetable kingdom. We have examined the nature of the seed—seen by what beautiful provision it is fed during its early germination—in what forms the elements by which it is nourished are introduced into the circulation of the young plant when the functions of the seed are discharged—and how earth, air, and water, are all made to minister to its after-growth. We have considered the various chemical changes which take place within the growing plant during the formation of its woody stem, the blossoming of its flower, and the ripening of its seed or fruit,—and have traced the further changes it undergoes, when, the functions of its short life being discharged, it hastens to serve other purposes, by mingling with the soil, and supplying food to new races. The soils themselves in which plants grow, their nature, their origin, the causes of their diversity in mineral character, and in natural productiveness, have each occu-

pied a share of our attention—while the various means of improving their agricultural value by mechanical means, by manuring or otherwise, have been practically considered, and theoretically explained. Lastly, we have glanced at the comparative worth of the various products of the land as food for man or other animals, and have briefly illustrated the principles upon which the feeding of animals, and the relative nutritive powers of the vegetables on which they live, and of the parts of animal bodies themselves, are known to depend.

In this short and familiar treatise I have not sought so much to *satisfy* the demands of the philosophical agriculturist, as to *awaken* the curiosity of my less instructed reader, to show him how much interesting as well as practically useful information Chemistry and Geology are able and willing to impart to him, and thus to allure him in quest of further knowledge and more accurate details to my larger work,* of which the present exhibits only a brief outline.

* *Lectures on Agricultural Chemistry and Geology.*

THE END.

PRINTED BY WILLIAM BLACKWOOD AND SONS, EDINBURGH.

WORKS

ON

AGRICULTURE AND RURAL ECONOMY

PUBLISHED BY

WILLIAM BLACKWOOD AND SONS

EDINBURGH AND LONDON

THE FORESTER.

A Practical Treatise on the Formation, Draining, and Fencing of Plantations; the Planting, Rearing, and Management of Forest Trees; the Cutting and Preparation of Wood for Sale: with an Improved Process for the Transplantation of Trees of Large Size. By JAMES BROWN, Forester, Arniston. A New Edition, greatly enlarged, with 109 Illustrations engraved on wood, in demy 8vo, price 21s.

"Mr James Brown, the forester at Arniston, near Dalkeith, has published his views of the subject in a sensible, concise, and useful manner: and we can now refer to his volume as *the book* to be recommended."—*Gardeners' Chronicle.*

"By a person who has for fifteen years had his attention almost entirely directed to the rearing of forest trees, and whose observations are conveyed in a clear and readily intelligible manner. The subject is methodically treated of in all its departments, from the laying out of the ground, the fencing and draining, to the cutting down of the trees, and the manner in which the wood ought to be prepared for the market."—*Scottish Farmer.*

"Excellent, clear, and thoroughly practical."—*Dundee Courier.*

"Beyond all doubt this is the best work on the subject of forestry extant."—*Gardeners' Journal.*

"A perfect manual of forest operations."—*Britannia.*

"This is an important work upon the subject of arboriculture. It has evidently been prepared with great care, and throughout gives proof of being the work of a practical forester."—*Literary Gazette.*

"A valuable adjunct to any library; and to a landowner, or person connected with the management of estates, or the cutting down and sale of timber, we should consider it almost indispensable."—*Derby Mercury.*

"This is essentially a practical work; it comprises the experience and opinions of an enthusiastic arboriculturist. There are many facts stated, moreover, which must make the volume highly useful to the professional man as a book of reference as well as instruction."—*Journal of Agriculture.*

A TREATISE ON LAND SURVEYING. By JOHN AINSLIE. A New and Enlarged Edition, embracing Railway, Military, Marine, and Geodetical Surveying, by WILLIAM GALBRAITH, M.A., F.R.A.S. In demy 8vo, price 21s., with an Atlas of Thirty-two Engravings on Steel by W. & A. K. JOHNSTON, and numerous Illustrations engraved on Wood, by R. E. BRANSTON.

"The best book on surveying with which I am acquainted."—WM. RUTHERFORD, LL.D., F.R.A.S., *Royal Military Academy, Woolwich.*

"The work of one who knew his business well. . . . . The only one in our language from which all necessary information may be obtained."—*London and Edin. Phil. Magazine.*

"I hardly expected, from the title, to have found such complete directions for marine surveying, a branch of the subject that has been too little attended to,—especially as to the proper observations on the rise and fall of the tides. I should like to see the book in every midshipman's berth in the Royal Navy."—CAPTAIN JOHN WASHINGTON, R.N., *one of the Admiralty Marine Surveyors.*

TRIGONOMETRICAL SURVEYING, LEVELLING, AND RAILWAY ENGINEERING. By WILLIAM GALBRAITH, M.A. 8vo, price 7s. 6d.

AN INTRODUCTION TO METEOROLOGY. Wherein the Laws of that important branch of Natural Science are explained by numerous interesting Facts, methodically arranged and familiarly described. By DAVID P. THOMSON, M.D. In Octavo, with numerous Illustrations. Price 12s. 6d.

"I consider it a most valuable treatise, and one likely to become popular when its merits are made known to the public."—*Sir David Brewster.*

"It appears to me that you have grappled successfully with your subject, and produced a useful and valuable volume, and one which, I have no doubt, will have a great circulation, if only for the number of curious and interesting facts described and collected in it."—*Sir John Herschel, Bart.*

"We borrow these refreshing passages from the Introduction to Meteorology of Dr Thomson—a work of a full and well-assorted mind—to which we shall often refer in the department now engaging our attention."—*Dublin University Magazine.*

"A complete treatise on the subject, including all the latest discoveries, inventions, and improvements. It is a great storehouse of facts scientifically and carefully arranged."—*The Economist.*

STEPHENS ON DRAINING. A Manual of Practical Draining. By HENRY STEPHENS, Esq., F.R.S.E., Author of the "Book of the Farm." 68 Illustrations on Wood. 8vo. Third Edition. 5s.

"A complete manual of draining in all its branches, clearly and concisely written; the various systems and practices in use are fairly discussed and commented upon, their peculiar advantages pointed out, and their applicability to the various descriptions of soil shown. The method of construction of the different drains is described, their relative cost summed carefully up, with plain and simple directions to the farmer to guide him in the choice of the particular system of draining he should adopt, as well as the mode in which it should be done."—*Bolton Free Press.*

STABLE ECONOMY: A Treatise on the Management of Horses. By JOHN STEWART, V.S. A New Edition, (being the Fourth,) in Foolscap 8vo, with numerous Woodcuts, price 6s. 6d.

"Will always maintain its position as a standard work upon the management of horses."—*Mark Lane Express.*

"The reader will find in it full instructions on stable economy in all its departments. The construction and ventilation of stables, the character and education of stable men and boys, the nature of their work as regards the grooming, decoration, and general treatment of horses, the habits and vices of horses, and the accidents to which they are liable, the nature, composition, and preparation of their food, the fitness for work, and the best method of keeping them in the best working condition, and the management of diseased and defective horses, are all fully discussed. There is no better book for the instruction of the groom."—*Gardeners' Chronicle and Agricultural Gazette.*

ADVICE TO PURCHASERS OF HORSES. Being a short and familiar Treatise on the internal formation of the Horse; the nature of Soundness and Unsoundness; and the Laws relating to Sale and Warranty; with Copious Directions for discovering Unsoundness prior to Purchasing. By the same Author. A New Edition, 18mo, 2s. 6d.

POPULAR EDITION.

LETTERS TO JOHN BULL, ESQ., on Affairs Connected with his Landed Property, and the Persons who live thereon. By SIR EDWARD BULWER LYTTON, BART. The Eleventh Edition, price One Shilling.

THE CHEMISTRY OF VEGETABLE AND ANIMAL PHYSIO- LOGY. By Dr G. J. MULDER, Professor of Chemistry in the University of Utrecht. With an Introduction and Notes by PROFESSOR JOHNSTON. In 8vo, with 22 Engravings, coloured and plain. Price 30s. bound in cloth.

ELKINGTON'S SYSTEM OF DRAINING. A Systematic Treatise on the Theory and Practice of Draining Land, adapted to the various Situations and Soils of England and Scotland, as drawn up by appointment of the Board of Agriculture, from the communications of Joseph Elkington. To which is added, a Treatise on Embankments and the Formation of Artificial Pieces of Water. By JOHN JOHNSTONE, Land-Surveyor A New Edition, lately published, illustrated by numerous Plans and Sections. 4to, price 10s. 6d.

THE PRACTICAL IRRIGATOR AND DRAINER. By GEORGE STEPHENS, Drainer, Member of the Nerecian and Wermlandska Agricultural Societies in Sweden. In 8vo, illustrated by Copperplates and Woodcuts, price 8s. 6d.

AGRICULTURAL PHYSIOLOGY, Animal and Vegetable. An attempt to give, in popular language, an outline of the leading principles of the Physiology of Animals and Plants, paying most attention to those principles which bear upon the art of the Manufacturer of Animal and Vegetable Food. By T. LINDLEY KEMP, M.D. In small 8vo, with numerous Illustrations, price 6s. 6d.

"The work before us is a portable compendium, designed for the use of practical agriculturists, and teaching the structure of the organs, and their functions, of the animal kingdom. The little book is a model of condensation, embodying information as intensely interesting as it is profoundly useful. It is plainly written, the best authorities cited, and, where plates or diagrams are necessary to explain the text, they are well and abundantly given."—*Bell's Life.*

PRACTICAL VENTILATION as applied to Public, Domestic, and Agricultural Structures. Being an elucidation of Plans, and suggestions of easy application, for ventilating every species of Architectural Structure; with remarks on Heating, Construction of Fire-places, Cure of Smoky Chimneys; and an Appendix, on the Ventilation of Ships, Steamboats, and Railway Carriages. By R. S. BURN, Engineer. Crown Octavo, price 6s.

"By far the most practical treatise on ventilation and warming that we have met with. . . . So simple and practical in the plans it recommends, that none can fail to understand them, or need be in any way alarmed at the expense of carrying them out."—*Glasgow Constitutional.*

"We commend the work."—*Mark Lane Express.*

"An excellent manual."—*Morning Chronicle.*

THE JOURNAL OF AGRICULTURE, and the TRANSACTIONS of the HIGHLAND and AGRICULTURAL SOCIETY of SCOTLAND. Published Quarterly. Annual Subscription, Twelve Shillings. Complete Sets may be had, viz.:—

OLD SERIES, 1828-43, 21 vols., cloth, lettered,......	£3	3	0
NEW SERIES, 1843-51, 8 vols., do. do.	2	2	0

SEVEN LITHOGRAPHED DESIGNS FOR THE IMPROVEMENT OF FARM COTTAGES AND STEADINGS. With Descriptions, Specifications, and Estimates; Remarks on the Accommodations required under the Modern System of Husbandry, and the Defects of Existing Farm Buildings. By JAMES CUNNINGHAM, Surveyor. Large 8vo, price 6s. 6d.

THE BOOK OF THE GARDEN; A Complete System of Gardening, Architectural, Ornamental, and Cultural. By CHARLES M'INTOSH, late Curator of the Royal Gardens of his Majesty the King of the Belgians at Claremont and Brussels, and now to his Grace the Duke of Buccleuch at Dalkeith Palace; author of "The Practical Gardener," &c. &c. With upwards of ONE THOUSAND ILLUSTRATIONS.

In Two Volumes royal 8vo, price £3, handsomely bound in cloth,

A NEW EDITION OF

THE BOOK OF THE FARM;

DETAILING THE LABOURS OF THE

FARMER, FARM-STEWARD, PLOUGHMAN, SHEPHERD, HEDGER, CATTLE-MAN, FIELD-WORKER, AND DAIRY-MAID;

AND FORMING

A SAFE MONITOR FOR STUDENTS IN PRACTICAL AGRICULTURE.

BY

HENRY STEPHENS, F.R.S.E.

This Edition is entirely rewritten, and embraces every recent application of Science to Agriculture; it is Illustrated with PORTRAITS OF ANIMALS painted from the Life, engraved on Steel by THOMAS LANDSEER and others; and with 600 ENGRAVINGS on WOOD by BRANSTON, representing the principal Field Operations, Implements, and Animals treated of in the Work.

SUBJECTS TREATED OF IN THE BOOK OF THE FARM.

INITIATION.

ON THE BEST OF THE EXISTING METHODS FOR ACQUIRING A THOROUGH KNOWLEDGE OF PRACTICAL HUSBANDRY.
DIFFICULTIES THE PUPIL HAS TO ENCOUNTER IN LEARNING PRACTICAL HUSBANDRY, AND ON THE MEANS OF OVERCOMING THEM.
THE DIFFERENT KINDS OF FARMING, AND ON SELECTING THE BEST.
ON THE BRANCHES OF SCIENCE MOST APPLICABLE TO AGRICULTURE.
PERSONS REQUIRED TO CONDUCT AND EXECUTE THE LABOUR OF THE FARM.
ON THE INSTITUTIONS OF EDUCATION BEST SUITED TO AGRICULTURAL STUDENTS.
ON THE EVILS ATTENDING THE NEGLECT OF LANDOWNERS AND OTHERS TO LEARN PRACTICAL AGRICULTURE.
ON OBSERVING THE DETAILS AND RECORDING THE FACTS OF FARMING BY THE AGRICULTURAL STUDENT.

THE BOOK OF THE FARM—Continued.

PRACTICE.

WINTER.

SUMMARY OF THE FIELD-OPERATIONS AND OF THE WEATHER IN WINTER.
PLOUGH, SWING-TREES, AND PLOUGH-HARNESS.
PLOUGHING AND PLOUGHING-MATCHES.
PLOUGHING DIFFERENT FORMS OF RIDGES.
PLOUGHING STUBBLE AND LEA GROUND.
OCCUPATION OF THE STEADING IN WINTER.
PULLING AND STORING TURNIPS, MANGOLD-WURZEL, CARROTS, PARSNIPS, AND CABBAGE, FOR CONSUMPTION IN WINTER.
FEEDING OF SHEEP ON TURNIPS IN WINTER.
ACCOMMODATION AFFORDED TO CATTLE IN WINTER BY THE STEADING.
REARING AND FATTENING OF CATTLE ON TURNIPS IN WINTER.
VARIETIES OF TURNIPS CULTIVATED.
CONSTRUCTION OF STABLES FOR FARM-HORSES.
TREATMENT OF FARM-HORSES IN WINTER.
TREATMENT OF THE FARMER'S SADDLE AND HARNESS HORSE IN WINTER.
FATTENING OF SWINE IN WINTER.
TREATMENT OF FOWLS IN WINTER.
RATIONALE OF THE FEEDING OF ANIMALS
ACCOMMODATION OF THE GRAIN CROPS IN THE STEADING.
THRASHING AND WINNOWING OF GRAIN.
FORMING OF DUNGHILLS AND COMPOSTS IN WINTER.
LIQUID MANURE, AND THE CONSTRUCTION OF LIQUID-MANURE TANKS AND CARTS.
SEA-WEED AS MANURE.
GAULTING OR CLAYING THE SOIL.

SPRING.

SUMMARY OF THE FIELD-OPERATIONS AND OF THE WEATHER IN SPRING.
ADVANTAGES OF HAVING FIELD-WORK ALWAYS IN A STATE OF FORWARDNESS.
CALVING OF COWS.
MILKING OF COWS.
REARING OF CALVES.
SOWING OF SPRING WHEAT.
DRILLING UP OF LAND.
SOWING OF OATS, BEANS, PEASE, TARES.
ROLLING OF LAND.
LUCERNE.
TRANSPLANTING OF TURNIP-BULBS FOR PRODUCING SEED.
SAINFOIN.
LAMBING OF EWES.
CROSS-PLOUGHING LAND.
RIBBING LAND FOR THE SEED-FURROW.
SOWING OF GRASS-SEEDS.
SOWING OF BARLEY.
TURNING OF DUNGHILLS.
PLANTING OF POTATOES.
PARING AND BURNING THE SURFACE.
FARROWING OF SOWS.
HATCHING OF FOWLS.

SUMMER.

SUMMARY OF THE FIELD-OPERATIONS AND OF THE WEATHER IN SUMMER.
ON THE HAY GIVEN TO FARM-HORSES.
SOWING AND SUMMER TREATMENT OF FLAX — HEMP — HOPS—TURNIPS — KOHL-RABI — THE CABBAGE — MANGOLD-WURZEL—THE CARROTS —PARSNIPS—RAPE—BUCKWHEAT—SUNFLOWER—MADIA—AND MAIZE.
THE RATIONALE OF THE GERMINATION OF SEEDS.
ON SOWING BROADCAST, DRILLED, AND DIBBLED—THICK AND THIN—AND AT DIFFERENT DEPTHS.
REPAIRING THE FENCES OF PASTURE-FIELDS.
DISPOSAL OF THE FAT SHEEP—AND FAT CATTLE.
MARES FOALING.
TREATMENT OF BULLS IN SUMMER.
PASTURING OF SHEEP AND CATTLE IN SUMMER.
WEANING OF CALVES.
PASTURING OF FARM-HORSES IN SUMMER.
SOILING OF STOCK ON FORAGE PLANTS.
WASHING AND SHEARING OF SHEEP.
ROLLING OF FLEECES, AND ON THE QUALITY OF WOOL.
SUMMER CULTURE OF BEANS AND PEASE.
WEANING OF LAMBS.
DRAFTING OF EWES AND GIMMERS.
MARKING OF SHEEP.
HAY-MAKING.
SUMMER CULTURE OF WHEAT—BARLEY —OATS—RYE—AND POTATOES.
SUMMER FALLOW.
REAPING OF TURNIP-SEED.
MAKING BUTTER AND CHEESE.

THE BOOK OF THE FARM—Continued.

AUTUMN.

SUMMARY OF THE FIELD-OPERATIONS AND OF THE WEATHER IN AUTUMN.
SOWING OF THE STONE TURNIP, AND ON THE SOWING OF TURNIP FOR SEED.
SOWING OF WINTER TARES—RAPE—CRIMSON CLOVER—BOKHARA CLOVER—RED CLOVER FOR SEED—AND ITALIAN RYE-GRASS.
PICKING AND DRYING OF HOPS.
SOWING OF WINTER BEANS.
PULLING, STEEPING, AND DRYING OF FLAX AND HEMP.
REAPING WHEAT, BARLEY, OATS, RYE, BEANS, PEASE AND TARES WHEN GROWN FOR SEED.
CARRYING AND STACKING OF WHEAT, BARLEY, OATS, BEANS, AND PEASE.
THE COMMON JERUSALEM ARTICHOKE.
REAPING BUCKWHEAT, SUNFLOWER, AND MAIZE.
BIRDS DESTRUCTIVE TO THE GRAIN-CROPS.
PUTTING THE TUPS TO THE EWES.
BATHING AND SMEARING OF SHEEP.
LIFTING POTATOES.
STORING POTATOES.
SOWING WHEAT, BARLEY, AND PEASE IN AUTUMN.
SOWING SEVERAL VARIETIES OF GRAIN TOGETHER.
PLANTING POTATOES IN AUTUMN.
THE EFFECTS OF SPECIAL MANURES.
ROTATION OF CROPS.
FERTILITY OF SOILS.
DISPOSAL OF THE FAT PIGS.
MANAGEMENT OF FOWLS.
ANIMALS DESTRUCTIVE TO POULTRY.

REALISATION.

DIFFERENCES IN THE PHYSICAL GEOGRAPHY OF FARMS.
CLIMATE AND ITS EFFECTS.
THE JUDGING OF LAND.
ESTIMATING THE RENT OF A FARM.
THE MODE OF OFFERING FOR A FARM.
NEGOTIATING THE COVENANTS OF THE LEASE.
ENTERING TO A FARM.
THE STOCKING OF A FARM.
CHOOSING THE SITE, ON BUILDING, AND ON THE EXPENSES OF ERECTING THE STEADING.
THE FARM-HOUSE.
COTTAGES FOR FARM-SERVANTS.
INSURANCE AGAINST FIRE AND DISEASE.
THE PRINCIPLES OF ENCLOSURE, AND ON SHELTER.
THE PLANTING AND REARING OF THORN-HEDGES.
THE BUILDING OF STONE-FENCES.
WIRE-FENCES.
EMBANKING AGAINST RIVULETS.
CONSTRUCTION OF FIELD-GATES.
DRAINING OF LAND.
IMPROVING WASTE LAND.
TRENCH AND SUBSOIL PLOUGHING.
LIMING OF LAND.
FORMING WATER-MEADOWS.
IRRIGATION.
TREATMENT OF DRAUGHT-STALLIONS.
BREAKING-IN OF YOUNG DRAUGHT-HORSES.
BREAKING-IN YOUNG SADDLE-HORSES.
TRAINING AND WORKING THE SHEPHERD'S DOG.
SLAUGHTERING OXEN, SHEEP, AND PIGS.
THE POINTS TO BE AIMED AT IN BREEDING THE MOST PERFECT FORMS IN LIVE STOCK.
DESCRIPTION OF THE ANIMALS WHOSE PORTRAITS ARE GIVEN IN THE PLATES.
ACCOUNT OF SOME OTHER BREEDS OF CATTLE AND SHEEP.
THE PRINCIPLES OF BREEDING.
SELECTION OF PARENTS IN BREEDING.
BREEDING IN-AND-IN.
CROSSING.
HIRING OF FARM-SERVANTS.
WAGES OF FARM-SERVANTS.
THE FARM SMITH, JOINER, AND SADDLER.
THE CARE DUE TO THE IMPLEMENTS.
MAKING EXPERIMENTS ON THE FARM.
CORN-MARKETS.
FARM BOOK-KEEPING.
CONCLUDING EXHORTATIONS TO THE YOUNG FARMER.
INDEX.

THE BOOK OF THE FARM—Continued.

EXTRACTS FROM NOTICES OF THE FIRST EDITION.

Professor Johnston.

"The best practical book I have ever met with."

Times.

"We assure agricultural students that they will derive both pleasure and profit from a diligent perusal of this clear directory to rural labour. The experienced farmer will perhaps think that Mr Stephens dwells upon some matters too simple or too trite to need explanation; but we regard this as a fault leaning to virtue's side in an instructional book. The young are often ashamed to ask for an explanation of simple things, and are too often discouraged by an indolent or supercilious teacher if they do. But Mr Stephens entirely escapes this error, for he indicates every step the young farmer should take, and, one by one, explains their several bearings. . . . . The business matter of a farm is divided by Mr Stephens into four parts, each bearing the name of the season that influences the operations that are performed in it. By this arrangement every operation is described as it takes its turn in the fields—described, we must in justice to the author observe, in so detailed and perspicuous a narrative, that no attentive reader can fail to comprehend the course he ought in practice to pursue. . . . . We have thoroughly examined these volumes; but to give a full notice of their varied and valuable contents would occupy a larger space than we can conveniently devote to their discussion; we therefore, in general terms, commend them to the careful study of every young man who wishes to become a good practical farmer."

Editor of American Reprint.

"No farmer who thirsts for knowledge himself, or who aspires to have his son rise 'to the true post of honour'—the dignified station of an intellectual and accomplished agriculturist—can justifiably deny himself such a work."

The Magnet.

"It is one of the chief recommendations of this work that its instructions are both clear and comprehensive, so that they are quickly understood and their merits appreciated; whilst the profusion of excellent cuts with which the text is embellished, brings the subjects treated upon fairly under the farmer's observation. There are few books of so high a character, or so eminently useful as this."

Farmers' Magazine.

"A work, the excellence of which is too well known to need any remarks of ours."

Inverness Courier.

"Mr Stephens has tasked himself to produce a great work—the most splendid we possess on the subject; and his title hardly conveys the full extent of his plan, which is more comprehensive and highly finished than any other rural cyclopædia we possess."

Bell's Messenger.

"Exhibiting in every page the combination of large experience, extensive observation, and a cultivated mind. . . . . One of the most unique and valuable works to be found within the range of agricultural literature."

Bell's Life.

"We know of no single agricultural work to be compared with this. . . . . Nothing can be more disinterestedly earnest than our recommendation of the 'Book of the Farm.'"

Agricultural Gazette.

"One of the completest works on agriculture of which our literature can boast."

Scottish Farmer.

"A most accurate and useful digest of all that has been ascertained by observation, experiment, and experience in relation to agriculture, more especially as conducted in our own country. By very many of the most enlightened and enterprising farmers and proprietors in Scotland, we know it has been held in the greatest estimation; and were we to seek information on any particular subject connected with rural affairs, it is certainly the book to which we should in the first instance refer."